Cold-Arid Deserts: Global Vernacular Framework for Passive Architectural Design

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By

Ana Molinar-Ruiz

D.Arch Committee:
David Rockwood, Chairperson
Dr. Andrew Kaufman
Jorge Loya
Dr. Marja Sarvimaki

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Dedication

To my loving husband.

Por tu cariño, paciencia, y apoyo en realizar mis sueños.

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My experience gathered through the completion of this doctorate project was very challenging and rewarding for me as a human, as well as for my future career in architecture. I would like to extend my deepest gratitude to my committee members David Rockwood, Andy Kaufman, Jorge Loya, and Magi Sarvimaki. The knowledge and experience they have shared with me throughout this project has been instrumental in the development of this dissertation. Without all their unwavering support, insight, and advice this project would not have been possible.

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Abstract

Among the most unforgiving climates, cold-arid deserts have inspired a myriad of solutions towards passive architecture. Developed over hundreds of years, lessons from vernacular architecture can be the key to challenges of the future.

> *"Since antiquity, man has reacted to his environment, using his faculties to develop techniques and technologies, in such a psychological balance with nature that humanity historically lived attuned to the environment" (Fathy 1986)*[1]

As concerns for the future of our planet steadily increase pertaining to the depletion of resources, energy consumption, and globalization, alternative solutions can improve the impact we have on our environment, as well as provide the ideal environment for us. The provision of housing for the rapidly growing population continually keeps architects and developers seeking ways to provide the most economically friendly, site specific design that can also be sustainable. Design solutions do not have to be costly or incorporate complicated modern technology to be sustainable and energy efficient. However, technological advancements continue to dictate the relationship between man and comfort. Can a blended principle of past solutions and modern technologies work together to improve the effects of climate on human environment?

This dissertation is meant to gather vernacular lessons to develop a valid framework, in order to create environmentally and culturally sustainable residential prototypes. Through a global analysis, a framework is extrapolated from existing vernacular case studies and modeled to test their relationships and possible improvements to prove their validity today within a single site, the Chihuahua Desert in North America.

[1] Fathy, Hassan. 1986. Natural Energy and Vernacular Architecture: Principles and Examples. London: University of Chicago Press.

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Introduction

Among the most unforgiving climates, Cold-Arid deserts have inspired very different approaches to architecture across the globe. Different conditions evolved due to unique geological conditions, material access, and human lifestyles. For centuries, architecture has been consistently modified to serve one primary purpose: protection and comfort. Humans have repeatedly adapted architecture to the environment, inventing systems and design parameters that reflect their climatic conditions. However, technological advancements in recent centuries led architecture through a different path that heavily relies on mechanical systems to achieve these goals.

Looking back to incorporate vernacular design principles can provide a more efficient and sustainable product, improving human comfort, reducing economic hardships, and reducing the negative impact architecture has had on the environment. For these reasons, it is important to analyze in depth and understand the different applications humans across the globe have developed as a response to their climate. Through centuries of evolution, this research aims to develop theoretical and quantifiable data of the vernacular design principles in regard to their effect on the environment and on the inhabitants.

This research aims to investigate those traditional design solutions and apply them where, due to changes in society, culture, economy and the environment, they were forgotten and discarded as a foundation for architectural design. For this process to prove successful, it is important to understand the theoretical implications, as well as some level of technical knowledge to improve or update systems that might no longer apply to existing culture.

The process consists of testing gathered scholarship in two different prototypes that will be modeled and tested in conjunction with current sustainability standards, as well as within adequate human comfort range. It will be interesting to determine if a global region archetype, in this case, the cold arid climate, can be accurately transplanted within other similar locations across the globe. For this dissertation, the prototypes will be applied in the city of El Paso, Texas, USA. The two different prototypes will be derived, with a focus to a particular archetype found throughout the cold-arid deserts of the world: a portable 'tent' structure, a hut that relies heavily on its surrounding environment, a dome that encompasses most comfort systems, and a 'complex' multi-family residence/ urban framework.

Ultimately, the result will be to determine whether vernacular architecture can provide a baseline for residential challenges in today's society and be a typical single-family home based on human comfort.

Part 1: Understanding Vernacular Architecture in Cold-Arid Deserts

Chapter 1: Premise

1.1: Defining Vernacular Architecture

> *"Buildings that belong to a place, that express the local or regional dialect" (Bonner 2006)*[2]

Broadly defined, vernacular architecture are empirical buildings designed and built without the intervention of professional architects, primarily derived from the needs of the local community or individual, and assembled with traditional building skills that use regional construction materials. The design is adapted through centuries to remain relevant to their developing lifestyles, cultural changes, as well as to meet environmental circumstances. Vernacular architecture is comprised mostly of dwellings, community spaces, cultural and religious buildings that tend to relate to the environmental context and available resources. They are built following traditional techniques and guidelines that each meet particular needs varying from space use to values, economy, culture, and lifestyle.

In recent history, the advancement of the human race has changed drastically. Particularly in the western world during the second half of the twentieth century, due to the industrial revolution, urbanization of cities, and rapid globalization, human growth has shifted to a modernized direction. (Vellinga 2007)[3]

> *"In the process, many vernacular traditions have become associated with the past, underdevelopment, and poverty, leading to the perception of vernacular buildings as obstacles on the road to progress rather*

[2] Bonner. 2006. Building Tradition: Control and authority in vernacular architecture. Oxon: Taylor & Francis.

[3] Vellinga, Marcel. 2007. Atlas of Vernacular Architecture of the World. New York: Routledge.

than as works of architecture that are well-adapted to local cultures, economies, and environments." (Oliver 1997 and 2003)4

This increase in globalization caused three primary changes that led to the abandonment of vernacular practices: lifestyle practices have changed due to social and economic structures, local culture and traditions have been muddled with widespread values and beliefs, and regional environments have been replaced with international materials and systems that remain independent of their location.

There are thousands of vernacular archetypes around the world, each having a defining set of factors that make them identifiable to a specific culture or region. They have evolved independently from one another as they must adapt not only to environmental conditions and material availability but to the cultural contexts in which they are found. The builders adapt traditions to reflect their lifestyle, which is among the most crucial factors to consider when analyzing vernacular architecture. For example, nomadic structures that can be dismantled may be prevalent in certain geographical locations, as well as separate times of year, while the same builder can have a permanent building to reflect their sedentary lifestyle during harsher months.

A common language found in vernacular architecture throughout the world, is the separation of spaces based on use, hierarchy of inhabitants, seasonal response to the environment, cultural separation (i.e. women space vs. men space), communal or private, and independent building or complex society arrangement. (Szabo 1991)[5] Most cultures are sedentary, that employ nomadic aspects and temporary structures to their lifestyles.

Due to the advancement of the human needs, this research will also investigate the vernacular features that no longer apply to today's society, due to culture, economy, or

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[4] Oliver. 1997 and 2003. of Vernacular Architecture of The World. Cambridge University Press.

[5] Szabo, Albert. 1991. Afghanistan: An Atlas of Indigenous Domestic Architecture. Austin: University of Texas Press.

environmental concerns. These criteria are partially selected through research and testing of actual thermal performance, as well as identifying current users, their positive or negative perception of the use/spaces, and if possible, incorporating innovative technologies to make them function for contemporary lifestyles, to provide a more comfortable living condition.

1.2: Psychology of the Cultural Landscape

As defined in most dictionaries, a landscape is all the visible features of a portion of land or a space on the surface of the earth. In the first uses of the term landscape, it referred only to a static picture, and then evolved to the view itself, including all the natural features (rivers, mountains, skies, etc.) it encompassed. (Encyclopedia Brittanica n.d.)[6] The fundamental message behind this paper is the gathering of vernacular archetypes found within cold-arid deserts around the world, reflecting the human response to architecture in similar landscapes. However, when studying the same landscape across a global scale, the vision of each landscape, albeit the same or similar physical climate parameters, changes depending on the perspective of a single user or a group of users, leading to the fascinating and unique approaches to architecture found across the world.

To be able to encompass a global array of scholarship and analyze it in a concise manner, it is important to find a way to take differences and find common ground. The purpose of this paper is to combine a vast selection of techniques, and resources, and approaches taken by communities that, although have similarities, have been separated for years, or centuries. Their lifestyle and their reasoning created different needs as to how to relate to their own environment. These differences are are what I believe to have been the catalyst for invention and approach to architecture. To understand their unique solutions for physical bioclimatic problems, one must also be aware of how their ‘sense

[6] edition, 13th. n.d. Encyclopedia Brittannica.

of place' and their psychological needs were as much of a factor as to how they could interact with their environment. An idea of a physical landscape interacting with their cultural landscape.

The term cultural landscape can be used to describe patterns of "mental, social, and ecological spaces that help to define human groups and their activities." (Wilson 2003)[7] To understand the human aspect, the landscape in which it developed should be an influence and catalyst rather than a passive result of human activity. The human aspect to understand is not only the direct culture and lifestyle of the inhabitants but their broader relationship to the built environment in which they are found. The term cultural landscape is best described as a:

> "*composition of man-made spaces on the land. A landscape is not a natural feature of the environment but a synthetic space, a man-made system of spaces superimposed on the face of the land, functioning and evolving not according to natural laws but to serve a community - for the collective character of the landscape is one thing that all generations and all points of view have agreed upon." (Jackson 1984)*[8]

The variances in vernacular development unique to global societies portray how humans adapt and modify space to interact between their physical and mental ideologies. Due to the subjectivity and relative immeasurability of the psyche, it is difficult to quantifiably measure the effects. However, there are many philosophical approaches for the effect vernacular architecture has on its users' mental well-being, as well as how the psychology of the user affects its vernacular architecture. The main approach encompasses the ways in which the individual (users) experience and action become the basis

[7] Wilson, Chris, and Groth, Paul, eds. 2003. Everyday America: Cultural Landscape Studies after J. B. Jackson. Berkeley, US: University of California Press.

[8] Jackson, John Brinckerhoff. 1984. Discovering the Vernacular Landscape. New Haven and London: Yale University Press

for shared social and cultural ideas and actions, and how then the social experience revolves and reflects into the individual's mind.

A series of vernacular case studies from 18 sites around the world, each with their own vernacular identity and response will provide an introduction to the power of the inhabitant to mold and control its landscape to fit its needs. The overall content gathered will be derived with these concepts in mind: the never ceasing relationship with the environment unique to every inhabited space where all environments and its inhabitants, no matter how similar, are insular. Their cultural landscape, which encompasses culture, social structure, politics, built environment, etc., is integrated into the landscape itself. (Jackson 1984)[9]

1.3: Human Comfort Standards

> *"A Machine is independent of its environment. It is little affected by climate and not at all by society. A person, however, is a member of a living organism that constantly reacts to its environment, changing it and being changed by it" (Fathy 1986)[10]*

Throughout the evolution of mankind, architecture has served as a critical component that has become more and more inclusive of human needs. Parting in the industrial revolution, we became more and more adapted to technology and active systems that control environmental conditions to create a favorable environment. However, in the process, we might have lost some basic human needs. We became accustomed to artificial air, to shades that prevent all heat from permeating into our spaces. We no longer seek the gentle breeze or the heat from the sun.

[9] Jackson, John Brinckerhoff. 1984. Discovering the Vernacular Landscape. New Haven and London: Yale University Press

[10] Fathy, Hassan. 1986. Natural Energy and Vernacular Architecture: Principles and Examples. London: University of Chicago Press.

Per the bioclimatic approach, man stands as the central measure in architecture, surrounded by human physical and psychological reactions to the physical (luminous & sonic), environmental (climatic), and elemential (special & animate). (Olgyay, 1963)[11]

It is not only necessary to debate the importance of physical comfort, but of intangible comfort as well. Balconies, patios, overhangs. Spaces shaded, and breezy that provide sanctuary evoke comfort as well as aesthetic satisfaction. The materiality, earth, landscape, and live plants play an important role in elevating the psyche of the perceived environment. Interior spaces must be adequately lit with daylighting that promotes productivity, health and mental energy at its highest efficiency.

Another aspect to consider is how the user interface can modify the microclimate associated with the building. As humans, there is a range of adequate thermal comfort, without going to extremes. However, that ideal temperature may vary from person to person. It is important to understand that a passive solution might need some conscious adjusting to the environment, whether it be to move across the building diurnally, learn to accept temperature fluctuations that can be addressed by a clothing change or a quick swim.

For this analysis to provide quantifiable analysis in human comfort, data for thermal comfort data derived from the Adaptive thermal comfort model (ATC): Air temperature surrounding the body. Radiant temperature that influences heat loss and gain from the environment that radiates to the user. Air velocity, which gains heat by conduction, radiation or evaporation, and releases heat to the exterior through ventilation. Relative humidity ratio between site-specific water vapor levels in the air. Further study of thermal comfort standards will be addressed in chapter 5.

[11] Olgyay, Victor. 1963. Design with climate, bioclimatic approach to architectural regionalism. New Jersey: Princeton University Press.

Chapter 2: Site

2.1: Identifying Geographical Locations

For the purpose of this dissertation, the study of vernacular archetypes will be focused on the cold arid desert climate classification and the semi-arid regions that surround them. According to Koppen climate classification, the cold arid climate is divided into two categories: Mid-latitude Dry Arid Desert (BWk) and Mid-Latitude Dry Semiarid Steppe (BSk). (Koppen 2016)[12]

Mid-latitude, or cold deserts, are geographically located around 30 degrees' latitude equidistant from the equator on both hemispheres and can be subdivided into categories based on their location or topography. The most common desert types found are continental, and rainshadow deserts. Continental deserts are caused primarily by dry air that loses humidity due to the sheer distance from the coastline, deep within the continent, and account for the greatest yearly and daily temperature change globally. The Gobi and Taklimakan deserts of Central Asia are examples of coastal deserts. (Oliver 1997 and 2003)[13] Rainshadow deserts are formed in between mountain ranges that block moisture rich weather systems and humidity from prevailing winds from reaching, creating extremely dry conditions. Rainshadow deserts include the Great Basin Desert and the Patagonia desert of the Andes, among others, located in North and South America respectively. (Dunn 1989, 1993)[14]

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[12] Koppen, Geiger. 2016. Climate Classification and Climatic Regions of the World. Accessed September 7, 2015. http://koeppen-geiger.vu-wien.ac.at/.

[13] Oliver. 1997 and 2003. of Vernacular Architecture of The World. Cambridge University Press.

[14] Dunn, Margery G. 1989, 1993. "Exploring your World: The Adventure of Geography." National Geographic Society

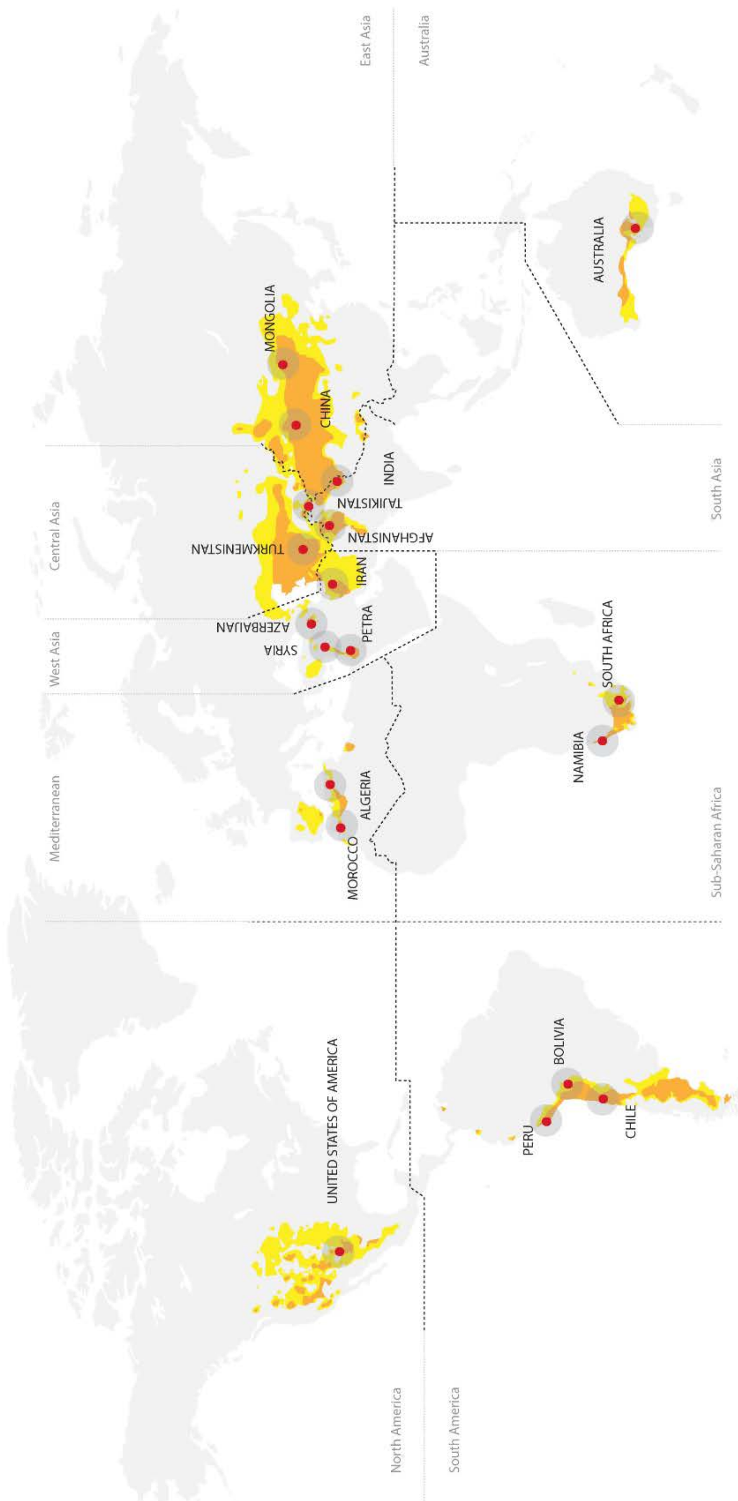

Figure 2.1 Koppen Climate Classifications Map: BWk (Orange) & BSk (Yellow)

To accurately portray the sites analyzed in the case studies, they will be identified by their geographical location, as well as the country and region they are located in. The sites chosen lie within the cold-arid biome. The following list includes the twenty countries that will be addressed throughout this dissertation:

North America- United States of America

South America- Peru, Bolivia, Chile

Africa- Morocco, Algeria, South Africa, Namibia

West Asia- Azerbaijan, Syria, Jordan, Iran

Central Asia- Turkmenistan

South Asia- Afghanistan, Tajikistan, India

East Asia- China, Mongolia

Australia- Australia

2.2: Climate Parameters

All cold-arid desert regions around the world follow similar environmental characteristics that have led to similar and different interpretations of architecture throughout. Although deserts are commonly known for their extreme heat, cold-arid deserts face harsher limitations for habitation due to the lack of water and the extreme temperature, not only high heat, but harsh temperature shifts from day to night, and freezing winters.

Desert climate aridity is identified by the proportion of evaporation is double the level of precipitation, also known as evapotranspiration, which means that the quantity of moisture cannot be regenerated since evaporation from soil and transpiration from vegetation is greater. Annual precipitation reaches a maximum of 10 inches annually, with erratic rainfall patterns. Drought patterns can last for several years that cause the soil to become harsh and impermeable, typically followed by a deluge that causes flooding and can lead to extreme damage to animals, vegetation, and humans.

Due to few clouds caused by the absence of moisture in the air, there is a constant of solar irradiation, varying in intensity depending on the type of desert and its geographical location. On average, deserts receive 3,000 hours of sunshine annually, deserts like the Sonoran Desert in North America and the Sahara in Sub-Saharan Africa can reach more than 4,000 hours.

Temperature varies vastly diurnally as well as between seasons. Because of low levels of humidity, solar radiation reaches the ground without limitation, where the absorption and reflection cause the temperature to increase during the day and rapidly change the air temperature during the night. Because of this, summer daytime air temperatures easily reach above 100 degrees Fahrenheit for more than 100 continuous days, while spring and fall temperatures have large diurnal cycles ranging from 30-50 degrees F. change between day and night, varying as much as 5 degrees per hour. (Trewartha 1954)[15]

Contrary to popular knowledge, desert terrain is composed of not only loose sand but of rugged and broken rock, as well as vegetated soil. “Loose sand characterizes only 2 percent of the terrain of North American deserts, 11 percent of the Sahara, and 30 percent of the Arabian desert”. (Nabokov 1988)[16] Erratic wind is common throughout the desert landscape, averaging 15mph and reaching upwards of 30 mph. When present, sand and dust storms can develop from small whirlwinds or twisters to violent blizzards, or persistent dust haze during the spring months.

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[15] Trewartha, Glenn T. 1954. An Introduction to Climate. New York: McGraw-Hill.

[16] Nabokov, Peter. 1988. Native American Architecture. United Kingdom: Oxford University Press.

Part 2: Framework for Passive Architectural Design

Chapter 3: Global Vernacular Component Library

Figure 3.1 Global Components: Vernacular Case Studies model & plans

The purpose of this chapter is to provide a brief background of vernacular architecture in 18 global sites. This brief comparison allows to identify common patterns and determine hierarchy within them. To further categorize the case studies, they are arranged into four main architecture types found in cold-arid desert biomes around the world: Tents, Huts, Domes, & Complexes. Scholarship gathered within each study varies greatly, however, all information gathered for these sites will provide the framework design guidelines for prototyping.

3.1: Case studies: Tents

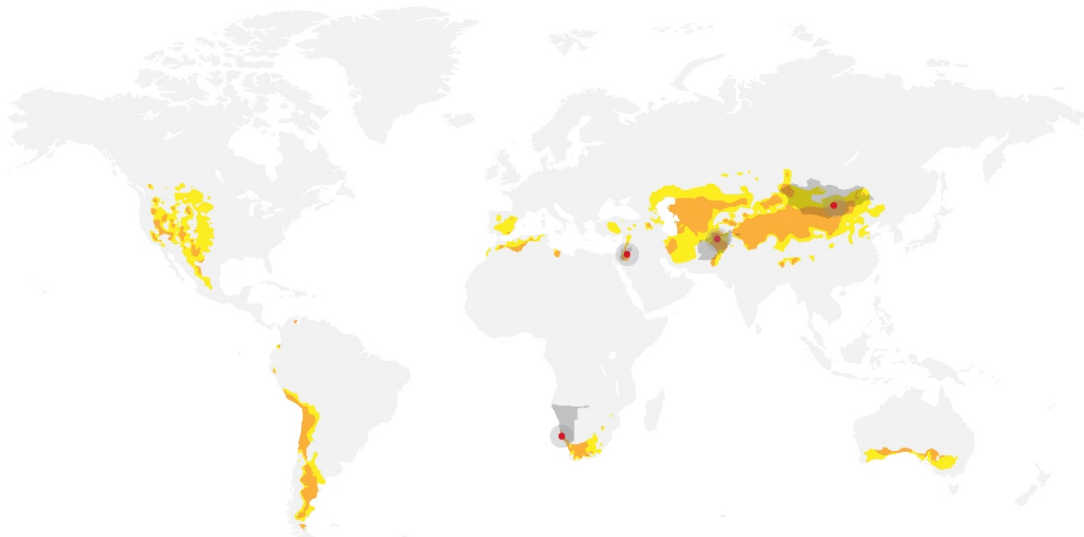

Figure 3.2 Global Components: Tent Case Studies

Tents are still a widely used dwelling type in hot and cold arid deserts across the globe. They were developed due to the non-sedentary lifestyle of the people, as well as in some places due to a minimal availability of construction materials. Their structure consists of a wooden indo-skeleton that holds a grass, felt, or leather material envelope. Grass tents are temporary structures that are used for a couple of weeks at a time before they must be reconstructed, while leather and felt tents can be assembled and disassembled many times with ease.

Used seasonally during the hot months, they are designed to accommodate an indoor fire with rooftop exhaust, as well as small overall dimensions for ease of heating in cool nights. Additionally, Yurts are adaptable to winter climates by adding a dirt wall along the walls to serve as thermal insulation. The design application for tents in modern lifestyles might not be ideal due to the need for permanent structures. However, parameters used in these archetypes can be applied in outdoor transitional spaces, shading devices, and temporary structures that are ideal for fluctuating climate control, and optimization of passive systems.

Case studies:

Sub-Saharan Africa | Namib Desert, Namibia

Southwest Asia | Petra, Jordan

Central & East Asia | Gobi Desert, Mongolia

Central & East Asia | Hindu Kush, Afghanistan

Figure 3.3 Nama Hut, Namibia[17]

The Nama hut was developed by the nomadic Southern Namib Desert Inhabitants. The hut is a small portable dwelling that can easily be dismantled and re-constructed, and light enough for transport.

In contrast to North African indigenous architecture, the Nama hut is a light-weight, skeletal structure that is non-sedentary. The structure consists of strips of reed that are rammed into the earth for structural stability in opposing directions. While the reeds are still green, they are bent to form the dome shape and covered in sewn grass mats when dried. Due to the extreme aridity of the climate, the grass fibers contract and swell in the rain to create an impervious surface. (Oliver 1997 and 2003)[18]. They also provide protection against heat by offset layering of the mats to allow for ventilation within the envelope. Once the structure is dismantled, the reeds are rendered inadequate for further use, but the mats can be reused in the next hut.

[17] (Image:, Nama African Ethnic Group - Nama Hut n.d.)
[18] Oliver. 1997 and 2003. of Vernacular Architecture of The World. Cambridge University Press.

Figure 3.4 Baida. Near Petra, Jordan[19]

Due to annual shifts between sedentary and nomadism, Petra's residents shift between black tents and alcoves. Although Petra is most commonly known for its sandstone monument tombs, the population resides mostly in black tents, with occasional rock refuges.

The black, goat hair tents serve as portable dwellings to fit the nomad lifestyle, as well as serve enough protection against the harsh climate. Individual tents can be placed together to make longer structures by joining the fabric with ropes to the light-weight wooden stakes that make up the structure of the tent, which is light enough to be put up by a single person in less than one day. The main attributes to the desert climate a tent offers are circulation through the many openings, shade from direct sunlight, protection from sandstorms and moderate protection against winter temperatures. They can be commonly found around rock formations used to shelter from strong winds. These rock

[19] (Caswell 2002)

alcoves can also be inhabited instead of the tent for colder months, or even converted by stone wall additions, becoming a more permanent residence (Oliver 1997 and 2003)[20]

Central & East Asia | Gobi Desert, Mongolia

Figure 3.5 Ger, Western Mongolia[21]

North Asia is familiar with extreme climate changes from day to night, from winter to summer, which led to seasonal architecture that is portable and modifiable. Here, the most common globally accepted non-sedentary structure thrives: the Mongol Yurt also known as Ger. Originally from Mongolia, they have spread through all of central Asia including Uzbekistan, Turkmenistan, and Kirghizstan, and typically consist of a wooden lattice wall held under compression, with a felt roof covering (Andrews 1973)[22].

The Ger is a circular portable dwelling designed for interior space maximization, stability against wind, efficient heating and insulation. It is generally constructed from

[20] Oliver. 1997 and 2003. of Vernacular Architecture of The World. Cambridge University Press.

[21] (Image:, Polyglottando n.d.)

[22] Andrews, P.A. 1973. "The White House of Khuransan: The felt tents of the Iranian Yomut and Goklen." Journal of the British Institute of Iranian Studies 11 93-110.

four straight trellises made from willow wood. The wall density changes according to season, enclosed with a double layer of felt panel insulation in winter or a woven reed mat for circulation in the summer, which have a hole at the top to be opened for smoke exhaust and light intake (Schubert 1971)[23]. The circular dome has a low center of gravity to protect against the harsh winds, as well as a narrow single opening facing the south.

Central & East Asia | Hindu Kush, Afghanistan

Figure 3.6 Black Tent, North Afghanistan[24]

The morphology of Afghan vernacular architecture is a derivative of not only local influence composed of a vast range of cultures, but of an amalgamation of surrounding countries from Mongolia to Pakistan, creating architecture designed to meet geographic conditions and climatic constraints, as well as largely influenced by a vast range of cultures and performance parameters placed by tradition. Here, a need for mobility is a primary factor for indigenous architecture, and with over twenty ethnic groups with

[23] Schubert, Johannes. 1971. Paralipomena Mongolica: Contemporary Kazaks: CUltural and Social Perspectives. Berlin: Curzon Press

[24] (Clarke 2015)

their own dialects and traditions, there are several variations to the non-sedentary dwellings (Szabo, 1991)[25]. The morphology differs by materials, articulation of space, light fenestration, thermal control, affected directly by its physical context and cultural needs. As aesthetic changes are found throughout, the major types of nomadic dwellings are the black tents.

Black tents are the most common of the three types of nomadic dwellings throughout Afghanistan. They are made of palas, a cloth strip woven from black goat hair, tied together to provide a continuous cloth that functions as both the roof and walls of the tent. Contrary to many desert architectures that use light colors to reflect solar radiation, the black surface has proven to reduce solar load due to the fact that black hair prevents short-wave radiation better than white hair, and absorbed heat is lost by convection before reaching the inside (Shkolnik 1980)[26]. Inversely, the black tent promotes circulation when the internal temperature rises above its exterior context, limiting their function to hot and dry climates.

Different tribes have differently pitched tents, yet a common difference happens due to climate. Vaulted tents are composed of ribs and frame to stretch the palas, usually designed with sturdier construction techniques for support during the winter storms. Peaked tents are created by the use of tent poles for smaller, lighter weight and easier assembly. (Ferdinand 1959)[27] The winter tents can also be reinforced with mud walls.

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[25] Szabo, Albert. 1991. Afghanistan: An Atlas of Indigenous Domestic Architecture. Austin: University of Texas Press.

[26] Shkolnik, Amiram, C. Richard Taylor. Virginia Finch, and Arieh Borut. 1980. "Why Do the Bedouins Wear Black Robes in Hot Deserts?" Nature 283 373-375.

[27] Ferdinand, Klaus. 1959. "The Baluchistan Barrel Vaulted Tent and its Affinities." Folk 1 27-50.

3.2: Case studies: Huts

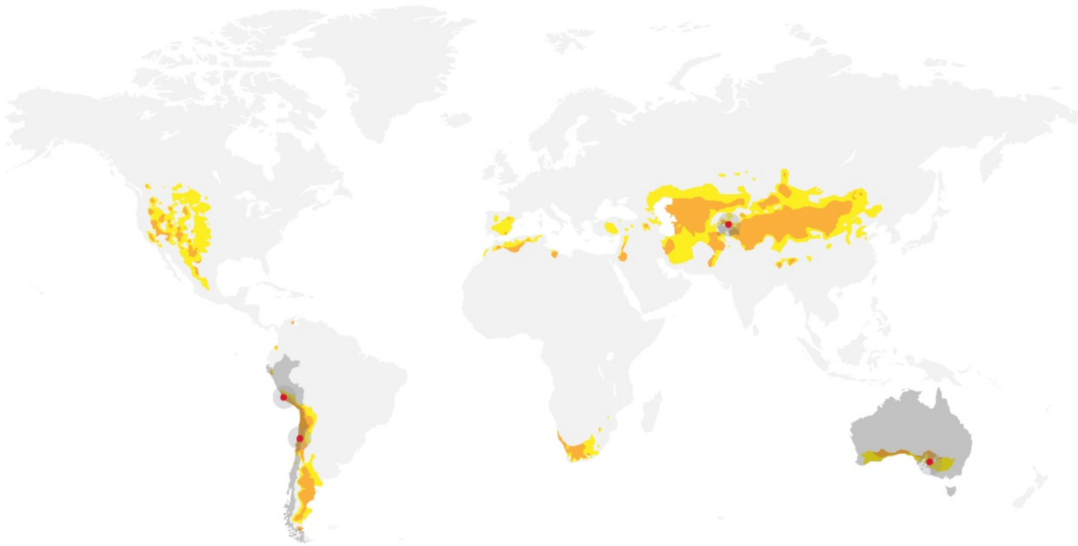

Figure 3.7 Global Components: Hut Case Studies

Although pitched and hipped roof huts are widespread globally, they are the least common used design in desert vernacular architecture, due to the fact that they require large amounts of wood forM construction, which is not an abundant material source. Since the structure is smaller than earth construction, the roofing material has to be light weight, such as grass thatching, and in turn, does not withstand the heavy winds and dryness of the climate. Even though there are examples of huts made from earth construction, the separation of walls and roofs as two separate entities allows breaks in insulation.

This type of construction is found primarily along special geological conditions, such as mountain ranges that provide wood and mountain side protection from high winds, Oasis underground-water availability, caves and underground dwellings. Existing vernacular examples of huts have not withstood the test of time, however, and are usually found in ruins. It remains important to analyze them due to the transportation advancement of modern time without limitations. It is also important since they do not require specialized knowledge to build as other archetypes.

Case studies:

Australia | Everard Ranges, South Australia

South America | Colca Valley, Peru

South America | Atacama Desert, Chile

Central & East Asia | Pamir Mountain Ranges, Tajikistan

Australia | Everard Ranges, South Australia

Figure 3.8 Domed Shelter, South Australia[28]

Australian Aborigines are a culture deeply rooted with the cosmos and the land, ideals that developed architecture that is not damaging to the land, impermanent. Due to the harsh climate of the land, there was little permanent architecture in the desert, with the use of diurnal and seasonal settlements in which large territories were inhabited during different times of the year.

Aboriginal architecture remained as such impermanent that it can be considered more as a temporary shelter than a settlement. Each shelter was composed primarily of spinifex grass thatching held up by cane ties driven into earth platforms elevated from the ground for wind circulation, protection against animals, and to damage the site the least possible due to their cosmological beliefs (Oliver, Encyclopedia)[29]. Cosmology drove many factors for the shelter, including the size, location, and proximity between them, making aboriginal vernacular architecture one of the most impermanent of the world.

[28] (Image:, Australian Indigenous Architecture n.d.)
[29] Oliver. 1997 and 2003. of Vernacular Architecture of The World. Cambridge University Press.

Desert dwellings were only used when the use of a slender spinifex grass-dome shade structure protected against extreme solar heat gain, while the circular path allowed for the circulation of breeze within (Paul Memmott 2009)[30]

South America | Colca Valley, Peru

Figure 3.9 Collagua House, Peru[31]

The Colca Valley in Peru is a seismic desert zone caused by a rainshadow effect from volcanoes and the Andes Mountains, blocking eastern winds carrying humidity. Here, cities grow along the Colca River, resembling cancha houses that date back to the Inca period (Oliver, Encyclopedia)[32].

A common indigenous style of house in Peru, the Collagua, is a remnant of the Inca civilization. This house typically has a series of three or more freestanding rectangular modules arranged along a perimeter to create an open courtyard in the center, sur-

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[30] Memmott, . 2009. "Biomimetic Theory and building technology: Use of Aboriginal and scientific knowledge of Spinifex grass." Architectural Science Review Vol. 52.2 117-125.

[31] (Image:, The Sustainable Nature of Peruvian Vernacular Architecture n.d.)

[32] Oliver. 1997 and 2003. of Vernacular Architecture of The World. Cambridge University Press.

rounded by stone walls that create narrow streets along the exterior perimeter between houses (Gutierrez, 1986)[33]. The buildings consist of stone walls encased with adobe measuring about two feet in width, with a pitched roof wooden structure thatched with straw. The roof is sometimes extended beyond the wall into a shallow veranda facing the courtyard. The only openings are the doorways to each building, as well as small squares along the top of the pitch roof in the kitchen module for heat exhaust.

South America | Atacama Desert, Chile

Figure 3.10 Quincha House, Chile[34]

The climate for The Atacama Desert is unique in that it has constant cloud coverage, yet extremely low precipitation due to diurnal thermal oscillation and prevalent maritime winds. San Lorenzo de Tarapaca is a city in the North of Chile that is under constant seismic activity that destroys its vernacular style of architecture, the adobe dwelling.

[33] Gutierrez. Placeholder. 1986

[34] (Becker 2006)

Traditional architecture consists of traditional adobe brick that is 24 inches thick with a wood structure roof covered with grass and clay. The exterior walls are very thick for thermal properties, yet the interior has lightweight partitions of a braided process known as quincha, where cane is braided and covered in clay (Bravo 2007)[35]. Under the seismic conditions of the land, Adobe has very low resistance to movement, leading to structural failure and collapse, while the quincha protects the interior without failing.

The shape of the dwelling tends to be single, large open space that is larger than other vernacular architecture within the surrounding countries. This large space is believed to have evolved due to the excessive cooling at night that passes through the openings and the thin roof structure, where ventilation actually negates the thermal massing of the structure (Whitman, et al. 2014)[36].

[35] Bravo, Samuel & Silva, Alvaro. 2007. "Comparative study between a proposed architectural prototype and heritage buildings to a hot-aric climate. The case of San Lorenzo de Tarapaca." International Conference on Sustainable Energy Technologies. . Santiago, Chile

[36] Whitman, C.J, G Armijo, M Garcia, and M.J. Errazuriz. 2014. "Learning from the past: Training for a sustainable future of the tourist sector in the Coastal Atacama Desert." World SB14 Barcelona 1-10.

Figure 3.11 Pamiri House, Tajikistan[37]

Tajikistan is characterized by high altitude, cold desert climate that guides the development of non-sedentary architecture. Due to its location, Tajikistan has a large influx of Yurts and Tents from both Mongolia and Afghanistan, but it also developed a traditional sedentary architecture for the Pamir Region. As with most houses that require heating over cooling, they are a single, sub-dividable room.

As a main characteristic of the traditional dwelling, Pamir architecture is a single, large space with a large roof that can encompass several buildings and their verandas. The large roof can be approximately 30 feet high with openings for smoke exhaust and supported by log beams (Oliver, Encyclopedia[38]). This roof layering serves as a buffer to the inner comfort from the harsh climate outside. The large space is then subdivided with clay platforms along the edges of lower enclosed spaces that serve as the individual bedrooms, with stone and clay walls, and no openings for windows.

[37] (Eduljee 2005-2014)
[38] Oliver. 1997 and 2003. of Vernacular Architecture of The World. Cambridge University Press.

3.3: Case studies: Domes

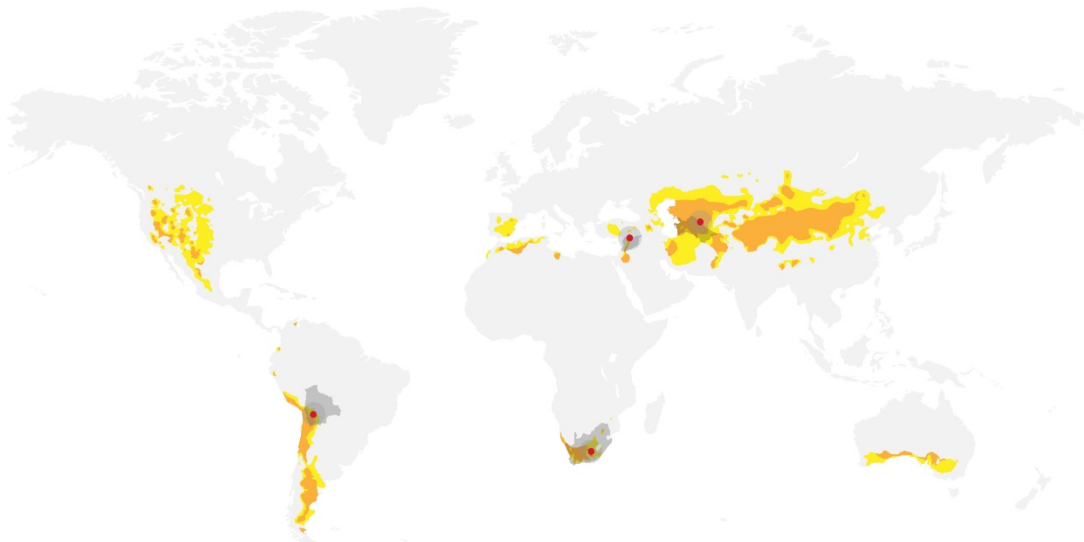


Figure 3.12 Global Components: Dome Case Studies

Domes, Cones, and Beehive building shape is widespread across vernacular architecture. Due to the lack of wood for post construction, this building shape is ideal for arid climate built of mud and clay bricks or stone that can be gathered and built on site while remaining structurally sound for decades. The use of these materials also mitigate heat exchange through thick walls for a low-heat exchange rate, keeping the interior at a comfortable temperature compared to the outside temperatures, which can vary diurnally by up to 30 deg. F.

Typically, a circular floorplan promotes air circulation while the height needed to achieve the dome shape serves to gather the hotter air above regularly used areas, exhaust it through openings and promote ventilation. The small openings are also strategically placed to provide daylight without glare. The wall/roof structure carries the load seamlessly to the ground, as well as sheds rainfall quickly to prevent leaking, water damage, and building decay. Domes still remain in use around the world and are commonly found replicated in contemporary passive architecture.

Case studies:

South America | Altiplano, Bolivia

Sub-Saharan Africa | Highland, South Africa

Southwest Asia | Idlib Steppe, Syria

Central & East Asia | Mary Province, Turkmenistan

Figure 3.13 Chipaya Village, Bolivia[39]

The Altiplano, or high-plain, is a flat land where cold winds sweep from the Andes to the west. Here, the Chipaya house is the vernacular tradition in the hot-cold climate. Even though the buildings are permanent, they are locally sourced and disintegrate into the landscape over time.

The Chipaya house is the only house in South America that is cylindrical to provide stability against the strong winds. The lower walls taper slightly up to 6.5 feet, then taper steeply to a thatched roof structure. The buildings are small at approximately 12 feet in diameter, freestanding, with a single wall opening as a door facing east for day lighting without solar heat gain (Oliver, Encyclopedia).[40]

The walls are composed of rectangular sod turf blocks, readily available grass and earth, that are staggered all the way to the roof, sometimes tapering together to form the roof as well. When thatching the roof structure, wood is taken from the skeleton of a cactus to use as rafters.

[39] (DOBES 2000-2015)
[40] Oliver. 1997 and 2003. of Vernacular Architecture of The World. Cambridge University Press.

Figure 3.14 Corbelled Hut, Williston, South Africa[41]

Along the Karoo in Northern Cape, South Africa, there are a wide variation of corbelled huts adapted from Mediterranean settlers as vernacular architecture for the area due to the abundance of stone and its protection against both extremes of hot and cold present in Central Karoo Region.

The huts are large, free-standing conical structures constructed entirely out of local stone. They are both circular and square in floorplan and are approximately 15 ft. in width up to 20 ft. height, single story. The wall is only opened with the door on one side and an opposing, smaller window, with a large stone lintel for structural support. The stone wall is about 30in in depth for thermal protection and about 7 ft. height before corbelling to a close point. Most huts were originally whitewashed, thus providing sequential stone protrusions along the corbelled roof to serve as maintenance access (Kramer 2007)[42] . It is believed that these structures functioned well to keep cool in the summer, but are largely uninhabited today due to inadequate protection against the cold winters.

[41] (Marais 2014)
[42] Kramer, Pat. 2007. "VASSA Journal." Vernacular Architecture Society of S.Africa 15-27.

Figure 3.15 Beehive houses, Sarouj, Syria[43]

The domed houses in Syria are an indigenous building style for the semi-arid desert that uses a single primary material for construction: earth. It is extremely economical and is simple to construct while protecting its inhabitants from the harsh desert elements.

The conical shaped building is constructed with sun-dried adobe bricks that are concentrically placed in circular layers, diminishing in diameter as each layer is added, usually between 10 and 16 ft. in height. There is no use for foundation or structural reinforcement. Stones are placed on the higher layers to provide access for restoration once the building is complete. There are only two openings in the walls. A door topped with a wood lintel, and a small circular opening near the top of the structure, about two feet in diameter to prevent structurally damaging the conical structure. Finally, the entire structure is covered in a second layer of adobe for additional support against erosion and applied a whitewash finish for solar reflectance (Oliver, Encyclopedia)[44].

[43] (Travel Adventures 2005)
[44] Oliver. 1997 and 2003. of Vernacular Architecture of The World. Cambridge University Press.

Figure 3.16 Mary Province, Turkmenistan[45]

Turkmenistan is located entirely in both arid and semi-arid topology. Its location is in close contact to an array of countries and serves as a passageway to Iran, Afghanistan, Tajikistan, Uzbekistan, and Kazakhstan. Its location has led to a variety of different types of architecture, from sedentary yurts for nomads, called ayul (Oliver, Encyclopedia)[46], to compact settlements in the oasis. One type of architecture that has been present from the first habitation of the area is the cupola house

The cupola is common in Turkmenistan as an ornamented roof structure for the great castles and mausoleums (Samarkand 2013)[47]. Along the Altrek River in the Mary province, houses made from unfired brick walls mixed with reed, and stone infill. The houses are rectangular in construction, with a cupola-shaped roof that resembles a yurt. This 'pile-dwelling' usually has two rooms and a veranda, joined by flat roof and with the central vaulted dome at the hearth of the house.

[45] (Sasin 2013)
[46] Oliver. 1997 and 2003. of Vernacular Architecture of The World. Cambridge University Press.
[47] Samarkand, Tashkent. 2013. "The artistic culture of central Asia and Azerbaijan in the 9th-15th centuries." IICAS Volume IV Architecture 280.

3.4: Case studies: Complexes

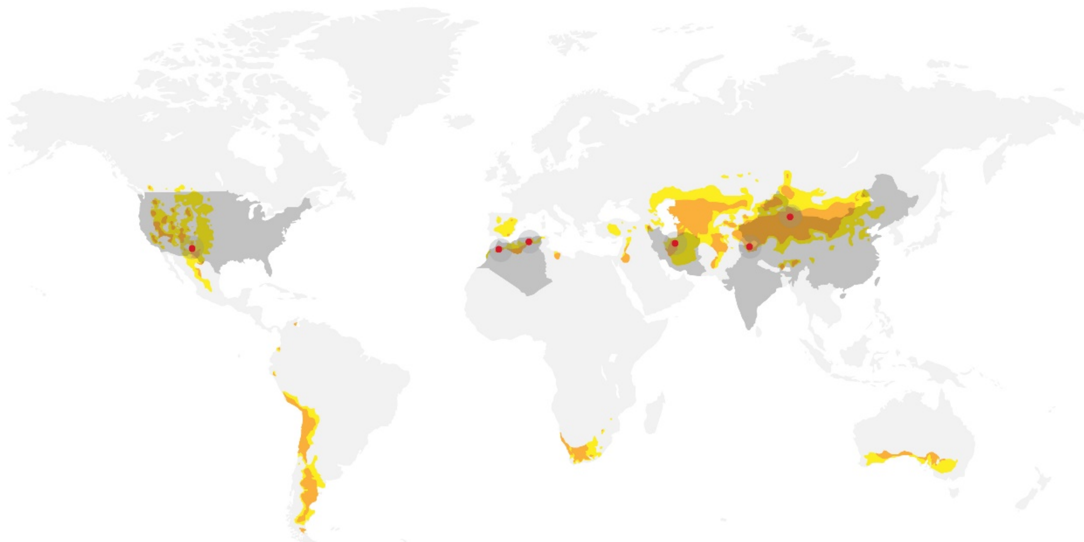


Figure 3.17 Global Components: Complex Case Studies

Unlike tents, domes, and huts that are free standing construction, complexes are communal dwellings and are noticeably larger in both floorplan and elevation. They are built as a unit that provides shading, protection from wind and dust storms while still allowing ventilation passages. They adhere to strict rules for design, with variable application from a single story independent house to an entire city structure up to 4 levels in height. They consist of adobe or earth construction with use of grass and stones as additives for stability in walls and roof, which is needed for the increased weight of materials.

Due to the lack of rain, the earth construction can withstand decades of use and have innovative systems implemented, such as wind towers, use of underground water and fountains for cooling, and courtyards as a staple for design. Complex developments are not only vernacular examples but remain in use to this day. They also developed a vast majority of passive systems and techniques applicable to the desert region.

Case Studies:

North America | Chihuahua desert, United States

Mediterranean | Draa Valley, Morocco

Mediterranean | Mzab Valley, Algeria

Central & East Asia | Leh Desert, India

Central & East Asia | Loess Plateau, China

Southwest Asia | Yazd Province, Iran

North America | Chihuahua Desert, USA

Figure 3.18 Mesa Verde, Chaco Canyon, USA[48]

The Chaco canyon ruins cover several acres of land, with different complexes that each have specialized design criteria. They are identified as built by the Ancestral Puebloan people, also known as Anasazi. The term Pueblo, which literally translates as village in Spanish, was coined by the Spanish explorers when finding the ruins due to their particular construction design. Although the settlements are widely no longer used as residences, they are vital to understand the ancestral approach to construction in North American vernacular architecture.

The complexes were designed to withstand drought, wind and water erosion, and extreme thunderstorms. Some of the pueblos like Mesa Verde were built strategically in limestone caves for shelter from the elements, particularly the extreme solar exposure. Others were strategically built in valleys that could accumulate snow in winter months to provide fresh water throughout the year, as well as small river tributaries, rather than larger rivers. The advantages of studying such complexes were the advanced development of microclimate design criteria the people had been living in for centuries. "Cha-

[48] (Jacobs 2013)

coan construction technology answered the formal requirements of buildings designed and built by a moderately complicated society." (Lekson 1984)[49]

Mediterranean | Draa Valley, Morocco

Figure 3.19 Ait Benhaddou, Morocco[50]

The Draa Valley, Morocco, is home to over 300 Ksours, earthen buildings that are adapted perfectly to the harsh arid climate, taking advantage of the natural oasis and mountains as protection, and using construction techniques to provide for thermal comfort and ventilation within.

The particular site of Ait Benhaddou has been a UNESCO World Heritage site since 1987 (UNESCO, 444)[51]. It was built as fortified complex of houses creating a dense urban fabric that use each other in protection from heat and create tunnels within to pro-

[49] Lekson, Stephen H. 1984. Great Pueblo Architecture of Chaco Canyon. Albuquerque: National Park Service.

[50] (Image:, Scenic Beauty of Telouet & Ait Ben Haddou 2015)

[51] UNESCO world Heritage Center. Whc.unesco.org/en/list/444

tect from heat and sandstorms (Baglioni 2009)[52]. Due to the thick walls for insulation and closeness of buildings lead to dark conditions, appropriate for outside use yet inappropriate for the inside of the dwellings. The development of a vertical light and wind shaft is prevalent in these structures, to mitigate internal comfort, where the vertical patio limits direct heat gain while providing passive lighting and ventilation to the interior of the complexes.

Mediterranean | Mzab Valley, Algeria

Figure 3.20 Beni-Isguen, Algeria[53]

The Mzab Valley in Algeria has a series of 'compact' cities, called Ksours, developed as an urban unit to address climatic concerns in the area, particularly outdoor thermal comfort, self-shading, and ventilation. These cities are designated as world culture heritage buildings by UNESCO since 1982 (Raverau, 1981)[54]. The Ksours are fortified buildings located in an oasis, usually located on southern slopes of rocky plateaus to pro-

[52] Baglioni, Eliana. 2009. "Sustainable Vernacular Architecture: The Case of the Draa Valley Skur (Morocco)." Sustainable Architecture and Urban Development 227-243.

[53] (Settlement 2010)

[54] Raverau. Placeholder. 1981

tect the inward-facing buildings from northerly winds. The compactness of the urban fabric creates a condition perfect for protection against solar heat absorption, direct solar radiation, as well creating a system for ventilation, generating a micro-climate within, a barrier protected with the palm trees of the oasis.

The architecture functions as a whole rather than the independent blocks that make it up. All buildings have to follow specific codes that limit exposure to direct solar radiation. The height of the complex must be enough to shade up to the neighboring wall across the narrow streets (Donnadieu et al. 1977)[55], only rooftops are allowed to be in direct exposure, with heavy flat roofs delay conduction of heat indoors and release it outdoors during the cooler nights, and no building can block the neighboring rooftop as it is necessary to absorb heat during the cold winters. Although the primary design of the city is to cope with the heat of summer, the semi-outdoors spaces are laid out with a southern orientation, taking advantage of heat storage capacities of the buildings (Ali-Toudert, et al. 2005)[56].

To compensate for the increased thermal inertia created by the compactness of the city, the use of indigenous stone, clay, and palm as the primary building materials provide a high thermal capacity that is later gypsum whitewashed for reflectance, as well as, (MR, Douglas S and J. 1997)[57]. Throughout the clustering of blocks, there are courtyards that remain small enough to remain shaded by the adjacent buildings and provide the only source of day lighting to the interiors.

An analysis of air temperatures, humidity, shade, and sunlight provide the factors to be considered for outdoor thermal comfort. In a study applied to the city of Beni-Isguen in Algeria, several sections of street alleys were measured. The results showed

[55] Donnadieu et al. Placeholder. 1977

[56] Ali-Toudert, Faiza, Moussadek Djenane, Railk Bensalem, and Helmut Mayer. 2005. "Outdoor thermal comfort in the old desert city of Beni-Isguen, Algeria." Climate Research Vol. 28

[57] Taha, Douglas S, and Haney J. 1997. "Mesoscale Metorological and air quality impacts of increased urbane albedo and vegetation." Energy Buildings 25 169-177.

relatively similar in the morning, setting of temperature changes in non-shaded vs. shaded streets, until a peak in temperature difference afternoon. To understand outdoor thermal comfort, deep canyons and tunnels that remain protected from direct solar radiation tended to remain cooler as expected, yet another factor influences temperature greatly: air mass exchange. The study proved that the streets farthest from the edge of the complex remained cooler than those along the edges due to adjacent exposed areas to heat along the outskirts of the city. Therefore, to promote outdoor thermal comfort, efficient shading can be provided by high aspect ratio of building scale vs. street scale, as well as limiting exposure to the body and the surrounding urban surfaces. High thermal materials are good for absorbing heat, yet when combined with high aspect ratio, nighttime heat release is slow and is counterproductive (Meier IA 2004)[58]. To promote ventilation through the streets, orient the street canyons along the main wind direction.

[58] Meier IA, Roaf SC et. al. 2004. "The Vernacular and the environment towards a comprehensive research methodology. " PLEA 21st Conf passive and low energy architecture 719-724.

Mediterranean | Ghadames, Libya

Figure 3.21 Traditional Housing of Ghadames, Libya[59]

Ghadames is located along an oasis surrounded by sandy and rocky desert, appropriating most of its construction materials from within the site. Here, the design of these heavy complexes was to control the high shift in annual and diurnal temperatures. The city, like other Ksours around the world, is well adapted for interior and exterior thermal comfort through compactness and self-shading, narrow, covered alleys, and thick earthen materials. (Aslund 1983)[60]

Construction materials and methods are the most important factor when designing a complex to withstand the desert climate. The walls are made up of sun-dried clay and straw bricks that are thicker along the lower floors, diminishing as they rise into the second and third floors, which is usually the highest that is structurally sound (Yusha, 1973)[61]. Within, the floors are constructed by palm tree trunks, palm leaves, stone and

[59] (Steinmetz 2013)

[60] Aalund, F. 1983. Ghadames: The Pearl of the desert. Libya: Architectural Conversation Planning

[61] Yusha. Placeholder. 1973

clay flooring, with a light colored gypsum covering along the roof and walls of the entire building envelope for solar reflectance. (Al-Zhubaidi, 2002)[62]

Central & East Asia | Leh Desert, India

Figure 3.22 Ladakh, India[63]

This region located at high altitudes in the Ladakh mountain range. Due to its altitude and strong winds, harsh climate developed vernacular architecture focused on solar exposure to address the cold winter months. Unlike other arid deserts, there is high cloud coverage due to the mountains, yet extremely low precipitation. The compact settlements developed along the south side of the mountain, with great importance given to building form, placement, materiality, and hierarchy of space usage.

The arrangement of the city of Leh along the Ladakh mountain range was planned as a complex rather than individual buildings. Through the use of solar exposure as the

[62] Al-Zhubiadi. Placeholder. 2002

[63] (Tibet Heritage Fund n.d.)

main guiding force, building form, city layout, and shape were derivate. (Krishan 1996)[64] First, all new development was placed on the south side of the mountain to maximize solar exposure. The main building material are sun-dried mud bricks for thick walls, where the lower portion is smaller thickness up to three feet thickness at the top of the wall, while keeping small openings for doors and windows uncovered, and they increase in size, varying from smaller lower floors and larger higher floors in the multi-story complexes. Although the cities are designed as a complex, they are not compressed, with wide open streets, without any shade structures.

[64] Krishan, Arvind. 1996. "The Habitat of two deserts in India: hot-dry desert of Jaisalmer (Rajasthan) and the cold-dry high altitude mountainous desert of Leh (Ladakh)." Energy and Buildings 23 217-229.

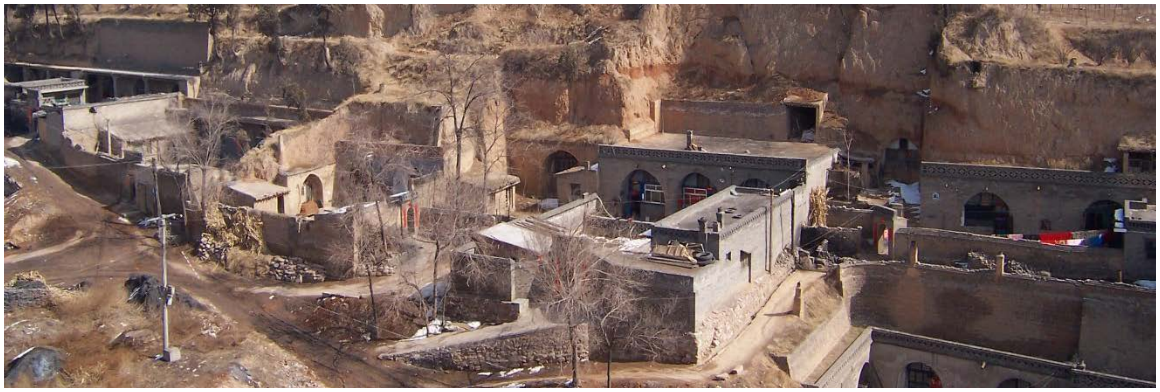


Figure 3.23 Cave Houses, Shanxi[65]

China is an extremely large and diverse country, containing the largest continuous arid and semi-arid desert area. These deserts are formed due to distance to the ocean, as well as the Siberian anti-cyclone. Here, there are many deserts and traditional architecture, with a fascinating desert climate solution within the Loess Plateau, the cave-dwellings. These dwellings provide for many opportunities for passive systems.

The cave dwellings consist of a series of rooms carved into the ground, surrounding a rectangular, and north-south facing open-courtyard with deciduous trees planted in the middle to provide shading in the hot summer and allow for solar radiation during cold months. The primary use rooms are on the east and west directions to avoid heat gain and have temporary use rooms along the south facing rooms (Bouillot and Huang 2008)[66]

The main insulation the house is provided is the earth that serves as the 7-foot thick roofing for the structure, functioning as not only protection from heat gain, but as

[65] (Pohelmann 2006)
[66] Bouillot, Jean, and Liming Huang. 2008. "Cave dwelling in china climatic conditions & microclimatic effects." Conference on Passive and low energy architecture. Dublin: PLEA

thermal cooling as well. The roof is also pierced within the rooms to promote cross ventilation through air inlets.

Southwest Asia | Yazd Province, Iran

Figure 3.24 City of Yazd, Iran[67]

The Yazd Province is home to an architectural language that is well adapted to the climatic constraints of the arid desert and to the limited resources available. With a 3,000 year history, (Ghodsi, 2013)[68] the city of Yazd has developed unique adaptations to the regions' arid climate, taken advantage of natural occurring groundwater reservoirs, and have led the way in vernacular cooling strategies and symbiotic application of components that function together to improve comfort levels.

Though there are many components applied to different buildings and scopes of the urban scale, such as covered alleyways, mud and adobe material in thick walls, there

[67] (Sajjadi 2011)
[68] Ghodsi. Placeholder. 2013

are four primary architectural components that work in harmony (Mahdavi, 2010)[69]. These are the Courtyard, the Windcatcher, Sardaab and the Qanats.

Buildings in Yazd are laid out very close to one another to shade and provide protection from wind storms and solar radiation, therefore limiting the amount of air circulation and day lighting the interior of the buildings can receive. This is where the courtyard plays an integral part of every building and is considered one of the main architectural components in the Iranian culture. The courtyard is a private space that is hidden from the main entry view, usually oriented along the southwest-northeast axis with an elongated design that enables shadows to be cast during summer for temperature control, to provide day lighting and circulation to the interior of the house (Keshtkaran, 2011)[70]. The building program is usually arranged along the courtyard. The south side only provides north daylight from inside the courtyard, since the south facing wall is thicker and has no openings to protect from the summer heat, and thus houses the Windcatcher, Sardaab, and offers a larger "floor to ceiling height" than the north side for heat rise (Akhtarkavan, 2011).

[69] Mahdavi. Placeholder. 2010
[70] Keshtkaran, Parinaz. 2011. Harmonization between climate and architecture in vernacular heritage. Beiza: Science Direct.

Chapter 4: Lessons Learned

4.1: Component Matrix

The previous chapter explored international case studies found globally within the cold-arid desert climate. Although each vernacular interpretation is unique, similarities became clear and certain methods of architectural response became apparent. Constant solutions seem to have been developed throughout the centuries and adapted to meet life-style, cultural, and environmental needs. The importance of this base of knowledge cannot be under-estimated. Through understanding the most common systems and unique interpretations, a fundamental framework for desert design can be established. In the following figure 4.1, the scholarship gathered is compared to similar interpretations found across the globe, to develop a matrix of components. Through this matrix, it is easier to compare the unique characteristics of tents, huts, domes and complexes at a fundamental level.

The matrix consists of the list of case studies organized by geographical location. Each case study was dissected into 9 categories: material, construction, structure, roof, environment, orientation, building type, and use. The categories were selected during the case study analysis, as the repetition of these components became increasingly apparent.

		AUSTRALIA	CHINA	MONGOLIA	INDIA	TAJIKISTAN	AFGHANISTAN	TURKMENISTAN	JORDAN	SYRIA	IRAN	NAMIBIA	SOUTH AFRICA	ALGERIA	MOROCCO	BOLIVIA	CHILE	PERU	UNITED STATES
GEOGRAPHY		AUS	ASIA									AFRICA				AMERICA			
		S	E			S		C		W		S		N		S			N
LOCATION		EVERARD RANGES	LOESS PLATEAU	GOBI DESERT	LEH DESERT	PAMIR MOUNTAIN	HINDU KUSH	MARY PROVINCE	PETRA	IDLIB STEPPE	YAZD PROVINCE	NAMIB DESERT	KAROO HIGHLAND	MZAB VALLEY	DRAA VALLEY	ALTIPLANO	ATACAMA DESERT	COLCA VALLEY	CHACO CANYON
NAME		GRASS HUT	CAVE DWELLING	GER / YURT	MOUNTAINSIDE COMPLEX	PAMIR HOUSE	BLACK TENT	CUPOLA HOUSE	BLACK TENT	CONICAL HOUSE	URBAN COMPLEX	NAMA HUT	CORBELLED HUT	KSOUR,KSAR	KSOUR, KSAR	CHIPAYA HOUSE	QUINCHE HOUSE	COLLAGUA HOUSE	MESA VERDE
MATERIAL CONSTRUCTION	FELT & LEATHER			●			●		●			●							
	GRASS	●	●	●				●			●		●	●	●	●	●	●	●
	WOOD	●	●	●	●		●	●	●	●		●	●			●	●	●	●
	EARTH		●	●	●	●	●	●		●	●	●		●	●	●	●	●	●
	STONE					●						●	●	●	●	●		●	●
STRUCTURE	SHADE	●	●			●	●	●			●		●	●	●			●	●
	COURTYARD		●								●				●			●	●
	TERRACE & PATIO		●			●		●			●			●	●			●	●
	NARROW ALLEYWAYS		●		●						●			●	●				●
ROOF	ROOF SHAPE	●	●	●	●	●	●	●	●	●	●	●	●			●		●	●
	ROOF OUTLET			●		●		●	●		●		●	●	●				
LEVEL	PLATFORM	●	●		●	●		●					●					●	
	DUGOUT	●					●				●				●				●
	NATURAL ENCLOSURE		●		●		●				●	●		●	●				●
ORIENTATION	ORIENTATION	●		●					●	●	●		●	●	●	●			●
	OPENINGS	●			●	●	●	●	●	●	●		●	●	●	●	●	●	●
	SPATIAL LAYOUT	●	●	●	●	●		●	●	●	●	●	●	●	●	●		●	
BUILDING TYPE	COMPACT		●		●						●			●	●				●
	TENSILE			●			●		●			●							
	MULTI-STORY										●			●	●			●	●
	PORTABLE			●			●		●			●							
USE	SEASONAL	●		●		●	●		●	●						●			
	DIURNAL	●	●	●	●		●				●	●	●						●

Figure 4.1 Vernacular Matrix of Components

The information gathered through the matrix is a clear and valid foundation for climate-responsive design. By selecting comparing them side by side, a hierarchy of components arises. For example, nearly all of the case studies analyzed apply the use of earth as part of their vernacular architecture. Whether it is used in the form of adobe, pressed mud, or brick modules, earth application is critical in desert design for its thermal properties, ease of application, and abundancy. It is used as the main construction material, or as an add on for insulation purposes.

The four categories tent, hut, dome, and complex share many similarities throughout. In the figure above, highlighted in orange are the individual points that every case study addressed. The 'complex' vernacular archetype is the most commonly found throughout the world that is still in use, as well as it is present in most geographical locations across the world. Tents are becoming less and less widely used due to the change from a nomadic to sedentary lifestyle.

The findings also establish a much-needed discussion between how vernacular architecture is not only driven by the accessibility to certain materials and in response to climatic constraints, but on cultural and social standards. As noted in the spatial layout category within the matrix, a great deal of consideration went into design of cardinal directions, based on religious beliefs, as well as segregation of spaces for women vs. men, or private vs. public. Many of the components accounted for in the matrix deal with subjective characteristics, locally driven, and not responsive to the climate or resources.

Due to the nature of this dissertation, emphasis was given to categories that dealt in response to a direct environmental stimulus.

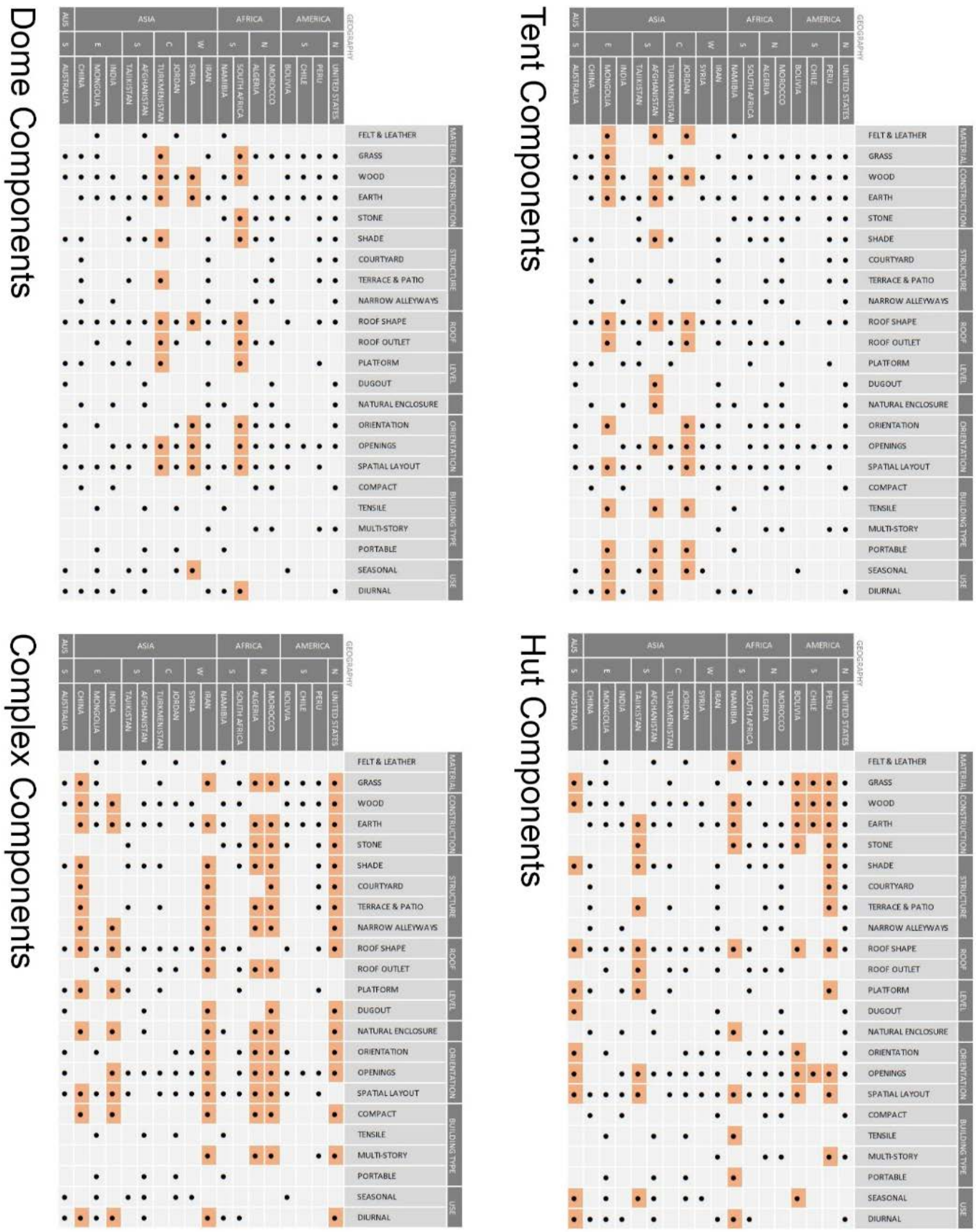


Figure 4.2 Vernacular Matrix of Components by type

4.2: Theoretical Analysis & Framework

Cultural heritage of any country plays an important role in achieving a sustainable environment. Builders were obliged to develop various logical climate responsive solutions in order to enhance human comfort levels.

When designing for cold arid climates, two of the main problems confronting the architect are to ensure the protection against heat and provide adequate cooling in the summer, as well as provide heat in the winter. There are many different approaches found in the case studies that attempt to solve the climatic issues. Although each site developed differently due to geological differences, as well as culture and lifestyle of the inhabitants, one thing remained constant: harsh summer heat and winter cold, extreme daily weather fluctuations, lack of humidity and limited water access.

Construction & Materials

Felt, or woven goat hair, is used in black tents as well as Yurt's. In black tents of Afghanistan, the black color in animal hair reduces solar load and promotes circulation by creating an internal stack effect, that when mixed with ventilation, increases the temperature inside the tent 18 to 25 degrees Fahrenheit, however, due to their poor performance in cold climates, felt is not used during winter season. (Shkolnik 1980)[71] This material is water tight and ideal for courtyard shading devices, as well as a thermal barrier in winter months to encapsulate the heat.

The use of grass is a common occurrence throughout the desert vernacular architecture. Although it is not used as a primary material, it is used in addition to earth and stone in different ways as a binding agent, as well as insulation. Woven reeds provide

[71] Shkolnik, Amiram, C. Richard Taylor. Virginia Finch, and Arieh Borut. 1980. "Why Do the Bedouins Wear Black Robes in Hot Deserts?" Nature 283 373-375.

waterproof roofing, spinifex grass is used as shading and insulation, and the straw bale is used as binding for structural purposes.

The primary materials used in vernacular architecture across the world are stone, clay/sand, and water. While wood is commonly used today, it has been undeniably used for centuries as an additional element to desert construction, rather than a permanent structural element; it is most commonly used in tensile or temporary structures for its stability and light weight.

Stone, sand, and clay are materials that are far easier to source on desert sites. Stone was usually procured from sandstone cliffs. In the Chaco area of North America, the cliff house sandstones consist of stone separated by a layer of shale, siltsone, and a harder laminated stone. This arrangement provided with a layer of rock that was easily quarried. (Lekson 1984).[72] The hardest material, although more difficult to quarry, is easier to reduce into flat-faced fragments to work as brick work.

Compressive strength of the rocks renders it unusable as a structural element, such as a column, therefore it is used in conjunction with wooden columns to provide the compressive strength it needs. The low tensile strength of stone is also a concern when building openings and ceilings. Because of this fact, vernacular architecture commonly creates small openings throughout to be able to continue its stone construction, however. When a large opening is needed, such as a doorway, a wooden lintel, with stone lintels reserved to smaller openings.

Mud mortar, made from clay and or sand mixed with water, is among the most common adaptations of desert vernacular architecture and is found in most huts and complexes, as well as an adaptation for tents for insulation in colder winter months. This material is also the easiest to source and is usually dug up on site. The downside of this pro-

[72]Lekson, Stephen H. 1984. Great Pueblo Architecture of Chaco Canyon. Albuquerque: National Park Service.

cess is the need for large amounts of water since it had to be sourced only from nearby rivers, reservoirs, or during the rainy seasons of late summer and early fall. (Lekson 1984).[73]

Sun dried bricks, or pressed mud, typically are found in conjunction with flat roofs. The Pakhsa walls in Afghani architecture are a typical approach to construction. When building mud walls, it was commonly built onto a 20” deep rock foundation to prevent erosion produced by capillary action of groundwater. Each brick consists of melon-sized dried mud pieces that are each about 20” long, allowing to dry between each layer, until a height of typically 7’-6” is reached, to a maximum of 9’-8”. ((Szabo 1991)[74]

Adobe is also among the most commonly used materials in the desert because it is feasible and practical. It is extremely resistant against direct solar irradiation because rooms can be warmed with little internal heat during cold and dry seasons. The heat transfer of adobe walls is ideal due to its high thermal capacity that takes a long time to transfer the heat from the exterior of the building, through the walls, to the interior, creating an insulation membrane that creates two different temperatures. Adobe delays heat transfer from inside to outside for about eight hours, (Keshtkaran 2011)[75] depending on the width, which means that the heat accumulated during the day is released to the inside during the cooler nights.

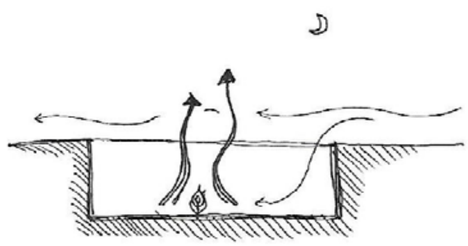
[73] Lekson, Stephen H. 1984. Great Pueblo Architecture of Chaco Canyon. Albuquerque: National Park Service.

[74] Szabo, Albert. 1991. Afghanistan: An Atlas of Indigenous Domestic Architecture. Austin: University of Texas Press.

[75] Keshtkaran, Parinaz. 2011. Harmonization between climate and architecture in vernacular heritage. Beiza: Science Direct.

Building envelope & structure

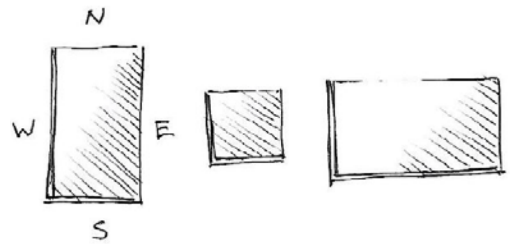
Courtyards are found throughout in most vernacular huts and complex archetypes around the world. They are of vital importance when designing in a desert climate because it promotes air movement by convection. Convection happens as warm air rises, it is replaced by cool air at ground level, if there is a heat source at ground level, such as direct sunlight or controlled fire, and a steady air flow will continuously bring cooler air into the courtyard. This effect works particularly well after sunset, which can raise the temperature up to 18-36 degrees F. cooler, (Fathy, 1986)[76] which permeates into the surrounding rooms until the next day when the sun reaches the courtyard floor directly.



To ensure the courtyard design works correctly, it has to be a rectangular shape that faces north-south, completely surrounded by tall walls that keep the ground shaded around 70% of the time. In the Chinese cave dwellings, they go a further step and plant deciduous trees in the middle to provide shading in the hot summer and allow for solar radiation during the cold months. (Bouillot and Huang 2008)[77]

[76] Fathy, Hassan. 1986. Natural Energy and Vernacular Architecture: Principles and Examples. London: University of Chicago Press.

[77] Bouillot, Jean, and Liming Huang. 2008. "Cave dwelling in china climatic conditions & microclimatic effects." Conference on Passive and low energy architecture. Dublin: PLEA



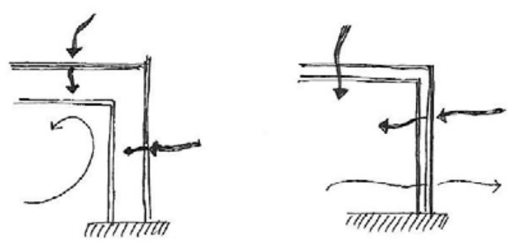
The microclimate created primarily throughout complexes around the world is widely documented. The alleyways/corridors created as negative space between buildings is actually critically designed and limited due to its influence on space acclimatization. Street orientation and aspect ratio are the most common criteria to consider when designing a functioning exterior space among complexes, as well as critical components to mitigate heat exchange within the buildings themselves. Alleyway floors and walls are heavily irradiated and must be controlled, as well as influencing wind flow at street level since that is the only ventilation that will eventually filter into the buildings themselves. (Arnfield 1990a)[78] Design techniques have been gathered through studies on the effects on thermal environment measured via a physical approach and comfort indices, as well as through adaptive approach that relies on subjective views gathered through surveys. Most of the studies involve investigating outdoor comfort using indoor comfort measurements, such as air temperature, humidity, and wind speed (Swaid et al. 1993).[79]

An energy-based model study determined that primarily street geometry influences radiation fluxes in human-energy balance. (Mayer & Hoppe 1987)[80] The study concluded that heat gain by a human body within a narrow alleyway in complexes where the height to width ratio equals 1, is lower in comparison to a fully exposed location due to increased shading. When factoring the evolution of comfort in day time through the sun's diurnal movement is strongly affected by the aspect ratio and orientation, due in

[78] Arnfield. Placeholder. 1990
[79] Swaid et al. Placeholder. 1993
[80] Mayer & Hoppe. placeholder. 1987

part to short-wave and long-wave irradiance amounts absorbed by the human body walking along the path. (Ali-Toudert & Mayer, 2005)[81]

The findings of the previous studies compared 5 criteria needed for psychologically equivalent temperature, or PET: Air temperature & humidity, wind speed, surface temperatures, radiation fluxes, and mean radiation temperature. Generally speaking, the prime orientation for the corridors is to run on a North to South orientation to allow longer time of protection against direct solar intake. Along the outskirts of the complexes, covered pathways prevent the stronger air mass exchange for areas that are exposed due to separation of buildings. Wind flow for ventilation at street level is promoted by a mixture of high and low elevation points within the corridor, where downhill buildings do not obstruct incoming wind flow while facing main wind direction in the site. Surface temperatures are addressed through a balance of exposure and shading from direct sunlight. It is critical that a near perfect balance is achieved to be able to withstand summer heat as well as mitigate winter cold.



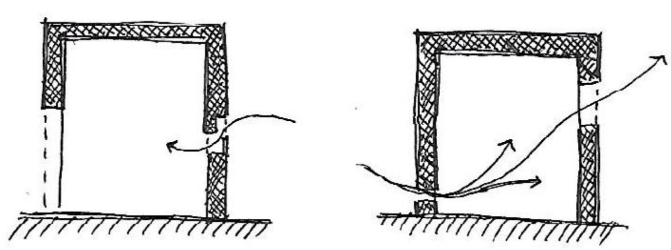
For radiation fluxes, the results suggest that a deep geometry is better for reducing the amount of time the wall/face is in direct exposure, regardless of solar orientation. (Ali-Toudert and Mayer 2005)[82]

[81] Ali-Toudert, Fazia, and Helmut Mayer. 2005. "Effects of street design on outdoor thermal comfort." University of Szeged Journal 45-55.
[82] Ibid

Window Openings

Windows serve 3 functions: to let in direct and indirect sunlight, let in air, and to provide view. It is rarely desirable to combine the three functions in a single architectural solution due to climatological limitations. A series of small openings that function like vents is usually applied in lieu of a few large openings. By breaking up the opening size and count, they serve for privacy, security, uniform permeability for air and ventilation, and provide increase protection against direct solar rays, and decoration. In Afghanistan, "They employ large apertures and permeable walls to increase air circulation and often sit on stilts, providing an extra surface to radiate heat away from the building" (Szabo 1991)[83]

Large openings are commonly prevented in desert archetypes. A large opening creates an environment equal to the exterior and breaks up wind ventilation creating a static environment, becoming as heat/cold (depending on the season) as the exterior. Large openings are also avoided due to extreme weather conditions, due to sandstorms and flash floods that can increase the chance of blowing off the roof of the building. Some cultures went as far as to provide T shaped doors that are wider at shoulder height and narrower at feet level to make the door opening as small as possible while still remaining functional. (Lekson 1984)[84]

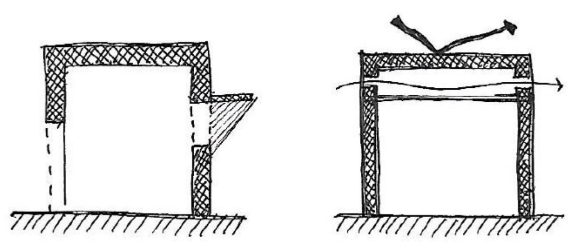


[83] Szabo, Albert. 1991. Afghanistan: An Atlas of Indigenous Domestic Architecture. Austin: University of Texas Press.
[84] Lekson, Stephen H. 1984. Great Pueblo Architecture of Chaco Canyon. Albuquerque: National Park Service.

An antecedent to the blinds was commonly used throughout the world, where fabrics and wooden slats were incorporated as a screen in chosen openings to regulate solar radiation and wind flow into rooms. They were also designed with a flat and narrow side, such as commonly used operable blinds, to deflect air downwards at the occupants, promoting the venturi effect to raise the heat and thus create circulation within the space. This was commonly used in small quarters. (Olgyay 1963)[85]

Roofing criteria

There are three primary roof shapes found throughout the desert biome: flat roofs, vaulted roofs, and domed roofs. Flat roofs are commonly found in the complex style construction. Due to the fact that flat roofs receive solar radiation continuously throughout the day, they are ideal for heating the building during the winter months. Due to the building density of the Ksours of Algeria, only the rooftops are allowed to be in direct contact with the sun, to prevent the interiors of the complexes to become too hot. The heavy, flat roofs delay conduction of heat indoors and release it outdoors during cooler nights. (faiza, 2005)[86]

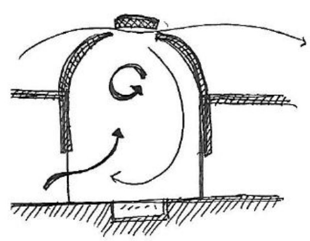


The combination of roofing materials with considerations for their reflectivity at the exterior surface, as well as the thermal resistivity of the material and thickness are of primary importance. The roof provides th largest area for heat absorption and dissipation,

[85]Olgyay, Victor. 1963. Design with climate, bioclimatic approach to architectural regionalism. New Jersey: Princeton University Press.
[86] Faiza. Placeholder. 2005

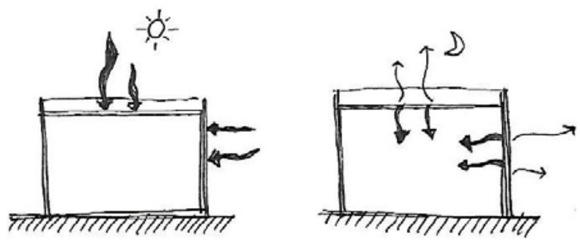
ad should be considered as priary factors for design. To aid in the efiiciency of thermal resistivity and reflictivity, a double roof, typically created by layering hollow brigks on the roof, with a thin layer of air in between helps as a shading device. Soil is sometimes used also as a good roof heat insulator, with plants that provide shade. This application is not so common unless the archetype is a dugout, due to the irrigation needed for the survival of the plants. However, it is beneficial because plants transpire and cool the air down prior to contact with the roof. Also, societal response to plants as opposed to living underground is desired. Since diurnal air temperature drops are considerable, user typically have either of the systems mentioned above. They have double function of shading the roof during the day and providing physiologically comfortable living and sleeping spaces at night.

A key design problem found throughout the archetypes is to reach a balanced heat intake for summer and winter months. With the suns radiation changes in a day or season, buildings are typically built to have the least possible thermal mass by orientation that maximizes heat dissipation.



Curved roofs have several advantages. On the inside of the building, curved roofs provide an elevated space that lies above the height of the inhabitants, allowing for warm air to dissipate through the roof and openings, preventing hot air from radiating into the space. The shape of the roof also promotes cool air to circulate at human level, as well as movement due to the Bernoulli Effect, which increases speed of exterior air as it lifts from ground level to overhead. (Foudazi, 2013)[87]

The shape on the outside increases the total surface area of the roof for heat transmission while minimizing the area where direct solar radiation can be absorbed. The corbelled huts in South Africa are particularly well adapted to dealing with solar radiation. Not only do they have an arched roof, but the shape of the entire building, from walls to roof is a seamless dome, minimizing direct solar irradiation to the minimum amount (Kramer 2007).[88] For most of the day, except noon, the building partly shades itself, at which time it acts as a radiator that absorbs heat from the sunlit areas and transmits it to the cooler side in the shade.

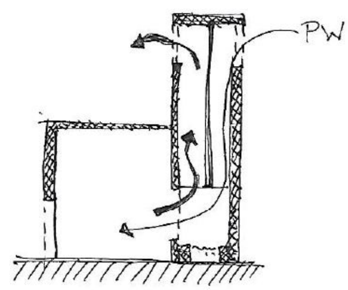


Differentials between indoor and outdoor air temperature are important considerations for climate control. When the outdoor ambien air temperature is higher that indoor temperatures, the exterior roof surface is heated no only through the absorption of direct radiation from the sun, but is also heated by the conduction of heat in contact with the outoor hot air, transmitted inward to mitigate for the cold air differential within the building, raising the interior air temperature. At the same time, it radiates heat that is absorbed by people and objects indoors, thereby affecting thermal comfort. (Fathy 1986)[89] Following patterns found in the Idlib Steppe, Syria and Western Cape Province,

[87] Foudazi, Fahimeh. 2013. Sustainable Cooling Solutions for Application in Western Cape Province, South Africa. Cape: Cape Peninsula University of Technology.
[88] Kramer, Pat. 2007. "VASSA Journal." Vernacular Architecture Society of S.Africa 15-27.
[89] Fathy, Hassan. 1986. Natural Energy and Vernacular Architecture: Principles and Examples. London: University of Chicago Press.

South Africa, where the dome and vents not only improve air circulation but also provide proper lighting without direct sun penetration. (Foudazi 2013)[90]

The Windcatcher is an ancient tower-like ventilation system that circulates the prevailing wind into the building to ventilate all year round. In Iranian culture, the Windcatcher is more common among wealthier families, which are larger and more elaborate (Ghodsi, 2013)[91]. It consists of a tall structure that protrudes from the roof of the building to minimize particle intake and is placed above a small interior pond to increase the humidity level entering the house. It is engineered to draw pressurized air vertically along the tower from prevailing winds (Roaf, 2008)[92]. The design consists of partitions that make a series of shafts with different functions. At one, the openings on top face the wind with positive pressure and operate to draw in breeze, while the other shafts have openings on the opposite side of the incoming wind with a negative pressure and function as outlet air passages, functioning through convection (Keshtkaran, 2011)[93]

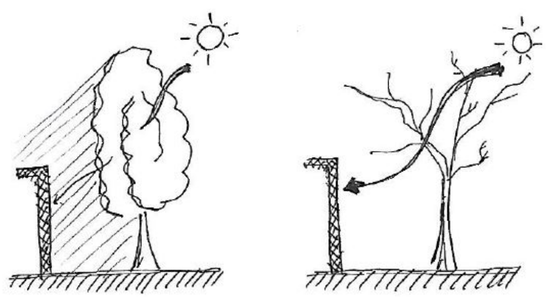


[90] Foudazi, Fahimeh. 2013. Sustainable Cooling Solutions for Application in Western Cape Province, South Africa. Cape: Cape Peninsula University of Technology.
[91] Ghodsi. 2013
[92] Roaf. 2008
[93] Keshtkaran, Parinaz. 2011. Harmonization between climate and architecture in vernacular heritage. Beiza: Science Direct.

Sun Orientation & Shading techniques

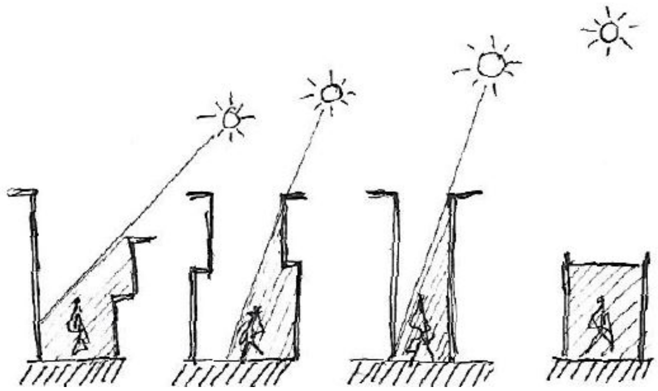
The position of the sun must be planned for all hours of the day at all seasons of the year. For direct rays of the sun, know angles of declination and altitude for summer and winter solstice, and autumnal and vernal equinox. These dates represent the extremes for which to design. Wind movement and humidity must be considered simultaneously with direct and indirect effects of the sun. East-West is the optimal orientation for solar daylighting, as long as there are wind movement systems in place. Priority should be given to solar orientation, rather than wind.

North facing rooms are ideal for illumination need and should be considered for most living areas. The indirect illumination received by the rooms is ideal for functionality, as well as limiting the amount of direct irradiation, which can cause the bedrooms to be too hot and cause glare that is uncomfortable.



South facing rooms must have shading that protect in summer months with small overhang, but let heat penetrate in winter months. Disadvantage is that south receives no wind since cool prevailing winds generally blow from northerly direction in the northern hemisphere. East facing rooms are only exposed to the sun’s rays from sunrise to noon. Walls cool down considerably by evening, making exposure more suitable for bedrooms. Shading of the east and west façade is ideal with architectural elements such as balconies, or open galleries and verandas, or introducing special devices such as contemporary brise-soleil to shield the openings.

Shading calculations are based on the maximum and average times throughout the year in under heated times the sun should strike the building, where the structure should be in shade. A chart of the sun's path is critical, as well as geometric and radiation calculations to describe the effectiveness of shading devices. (Olgyay 1963)[94]



Shady alleyways in complexes are also a great analysis for how to prevent heat gain. Generally, a building with a façade opening to the west is the worst. By calculating the angle of the sun altitude, and designing to cover at the summer angle of latitude, and allow for sunlight to penetrate at a winter angle of latitude heat gain of the surrounding environment can be incorporated. For a complex series of buildings, they can shade each other if their façade faces west to east, by designing the height according to the width of the street and the angle of altitude of the sun (Fathy 1986)[95] By having narrow, zigzagging alleys receive a minimum of radiation, reduce the effect of natural storms and violent winds, while creating areas that are shaded, cool and comfortable throughout the urban settlement. They are also ideal spaces that stay warm during cold nights and in winter.

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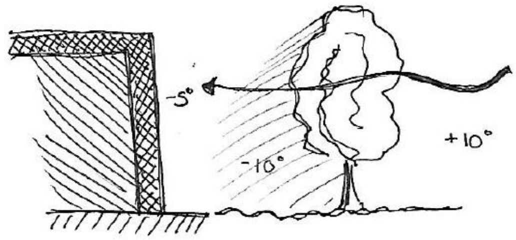
[94] Olgyay, Victor. 1963. Design with climate, bioclimatic approach to architectural regionalism. New Jersey: Princeton University Press.

[95] Fathy, Hassan. 1986. Natural Energy and Vernacular Architecture: Principles and Examples. London: University of Chicago Press.



Vegetation is also a great addition for any building. “Temperature around buildings can be either tempered or aggravated by the nature of the surrounding surface” (SKAT 1993)[96], Particular attention should be placed to spaces that are used on the exterior as well, such as sitting areas, entryways, and walkways.

Wind Orientation

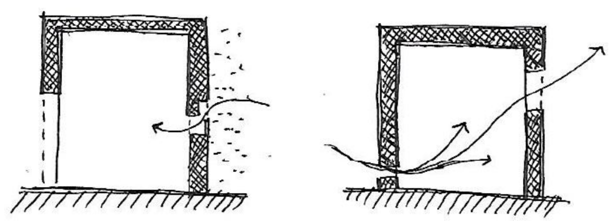
Although vernacular architecture tends to deal more with solar control, wind is critical for acclimatizing a space. Once the necessary design features are set to limit/promote heat absorption, wind is needed to create spaces that are better suited for human habitation, as well as to transfer the heat and cold air throughout the building. It is important to design the site in consideration of the prevailing winds, particularly during the hot season. By aligning the building parallel to winds when in an urban, dense environment, wind tunnels are influenced. In contrast, buildings should be placed perpendicular to the prevailing winds when there is a free-standing structure, to take the most advantage.

According to the bernoulli theorem, the pressure of a moving fluid decreases as its velocity increases. The principle is used commonly throughout the archetypes, where air is channeled through a large opening towards a smaller opening to work as an air outlet, working as a funnel with accelerated wind speed as it passes in between. As a large mass

[96] SKAT. 1993. Climate Responsive Buildings- Appropriate Building Construction. Accessed February 14, 2016. http://collections.infocollections.org/ukedu/en/d/Jsk02ce/5.2.html

of air accumulates at the large opening and the increased volume of air must pass through the smaller opening at the same rate, thus lowering the air pressure with respect to the atmospheric pressure in the lower part of the side tube. This air is drawn up the side tube by the pressure difference which is proportional to the square of the velocity.

The implementation of the Bernoulli principle is an indispensable principle that is found in all archetypes across the globe. Due to the randomness in air speed and direction wihin the cold-arid archetypes, the control indoor air movement is crucial in passive ventilation. The interior airflow caused by the pressure differential creates steadier air movement that depends on the suction of air from low to high air pressure rather than relying on the exterior cross ventilation, which can be too static or too fast. The relationship between a larger intake and smaller air outlet is critical.



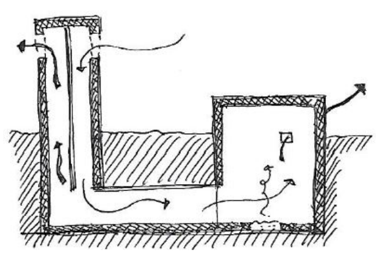
Typically, air movement is steadier and faster when large openings are provided on the leeward side of the building, and smaller openings are provided on the windward side. It is common to find a structurally integrated horizontal wind scoop along the windward side. The badger, (Oliver 1997 and 2003)[97], consists of a recessed niche on the external wall of the structure that runs between two vertical posts. The mid-wall of this system intakes cool down the internal through by encouraging ventilation Vents should be placed right underneath the roof for hot air outlets.

[97] Oliver. 1997 and 2003. of Vernacular Architecture of The World. Cambridge University Press.

The lessons learned state to provide areas with cool and refreshing breezes a shaded area. It is more efficient to provide courtyards on the leeward side that are nearly enclosed to the prevailing winds, with controlled air intake through small rows of openings. This courtyard space will create a zone of low pressure, where airflow goes over and around the building, thuss inside the shaded space as a result of the Bernoulli principle. This ensures steady airflow sue to suction through the small openings.

Water Integration

A traditional approach to the courtyard in Yazd, Iran, is sunken from the main level of the house to allow for more shading within and to be closer to the Qanats (underground water canal) for water cooling, and the earth removed during construction is used in the construction of the building. (A'zami, Yaserbi, Salheipoor, 2005)[98]. The Sardaab, (basement), is an integral part for the harmonious relationship between the components. The earth surrounding the Sardaab and the running water from the Qanat that runs through the entire Yazd region, provide cool air to be circulated into the habitable space by the pressure of the Windcatcher throughout. Water is very important in increasing humidity to promote thermal comfort, so in sites that do not have access to underground water, a small fountain or pool centered in the courtyard serves to cool the air.



[98] A'zami, Yaserbim Salheipoor, 2005

4.3: Diagrammatic guidelines

The following guidelines were created as a simplified version of the rules followed when developing each model. During the modeling process, I noted that placing specific limits on dimensions and materiality would not make possible any sort of data comparison or alternate modeling since the results yielded would create an exact replica each time. Therefore, a series of general parameters was derived from commonalities within each that can later be tested in the design project prototypes.

For this purpose, a set of diagrammatic guidelines proved to be more effective if they generally applied to all the different types of architecture. Once the rules were set, simple diagrams were created to represent the functionality of each system and/or design rule found in the vernacular precedent.

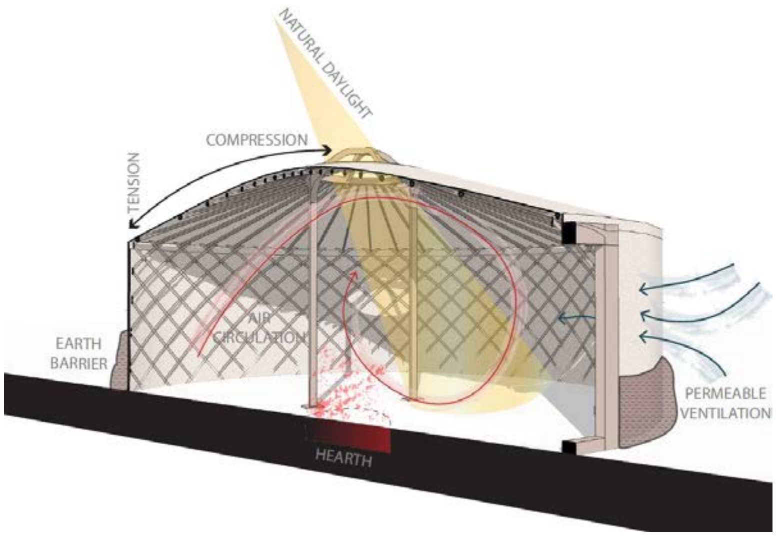


Figure 4.3 Diagrammatic Guidelines – Tent derivatives[99]

Properties of tents will be primarily analyzed for their indoor micro-climate capabilities during winter months:

- Use the black felt or woven goat hair as window louver sealers during winter months.
- Use the black felt or woven goat hair in the summer months as well as a screen protection from dust and insects that provides permeable ventilation.
- Design a circular space with a central hearth if heating needs are prevailing.
- Use of central skylight instead of windows to provide for adequate daylighting.
- Incorporate tension and compression capabilities of wood slats into seasonal shading devices.

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[99] Source: Drawn by Author

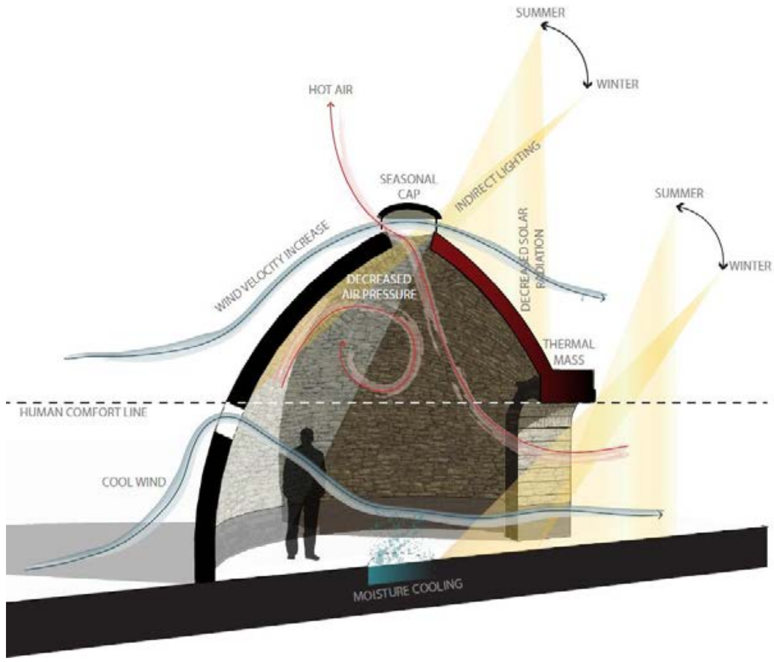

Figure 4.4 Diagrammatic Guidelines – Dome derivatives[100]

Properties of domes will be primarily analyzed for their human comfort and air pressure and moisture control techniques:

- High ceilings above regular occupancy in spaces occupied during the day.
- Domed roof receives less direct solar radiation intake
- Curved roods increase wind velocity outside and decrease pressure, inducing hot air inside to flow out.
- Hot air is pooled at the top of the dome while cool air circulates below.
- Operable opening at the top of the dome to release or contain hot air.
- Use stacked material as a single wall/roof membrane for insulation benefits and minimize porosity.
- Vent at the top of the dome to improve indoor ventilation.

[100] Source: Drawn by Author

- For winter use spaces, flat roofs are better suited for heat transfer.
- Opposite openings should be designed smaller on the prevailing wind side and larger on opposite side for the Venturi effect.

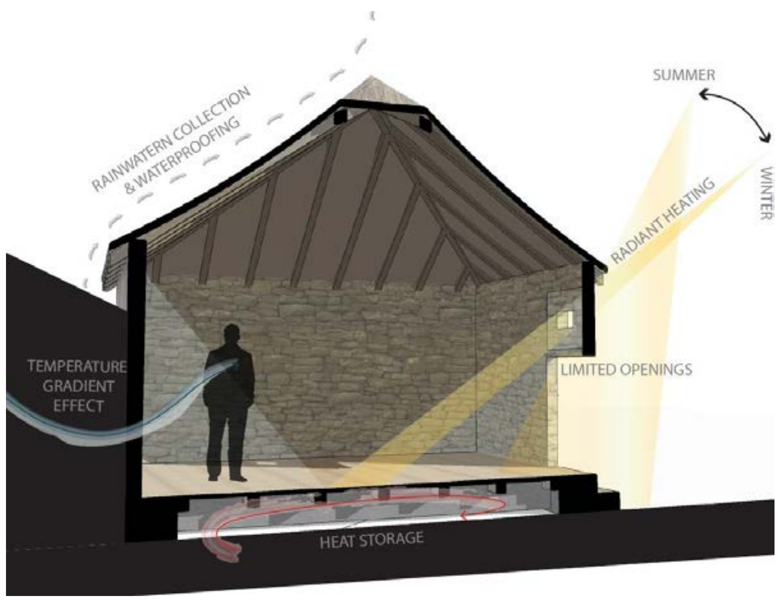

Figure 4.5 Diagrammatic Guidelines – Hut derivatives[101]

Properties of huts will be primarily analyzed for their use of the surrounding landscape as a weather barrier:

- Locate building on mountain side along prevailing winds.
- Locate site between 1,000-2,000 feet above valleys for cooler and evaporative systems control.

[101] Source: Drawn by Author

- Orient the narrow side of the building along the South façade for minimal solar heat gain.
- Design exterior use spaces on North façade.
- Locate building within natural or artificial context that maximizes 12:00 - 3:00pm shade.
- Avoid valley bottoms perpendicular to prevailing winds to prevent solar reflection.
- Recess buildings into the earth for geothermal cooling and insulation.
- Elevate the building on platform as a heat storage cavity.

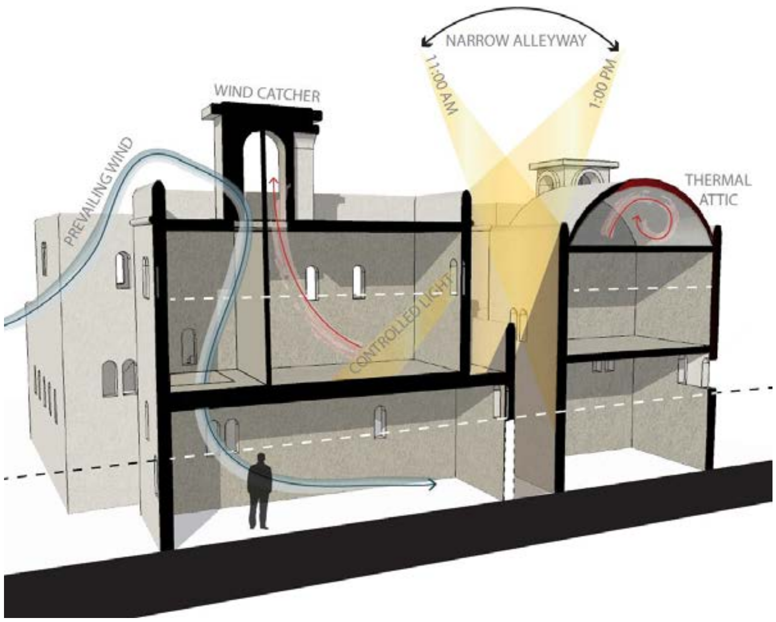

Figure 4.6 Diagrammatic Guidelines – Complex derivatives[102]

Properties of complexes will be primarily analyzed for their innovative systems for thermal comfort:

- Primary openings and access should face inward.
- Plants and water landscaping provide protection against extreme wind and sand storm conditions, as well as reduce the external temperature by up to 10 degrees.
- Keep primary streets linear and parallel to increase ventilation in the core.
- Block streets and paths inside to protect from storms.
- Each building has to provide courtyard to reduce radiation and provide adequate daylighting and ventilation to inside of buildings.
- Buildings must be in contact with each other to reduce heat absorption, as well as have narrow alleyways within to create a shaded microclimate.

[102] Source: Drawn by Author

- Height restrictions enforced to keep roofs unshaded 60% of day time to remain hot in winter months.
- Keep heavy-use pedestrian alleys at 15’ width min. Reduce width of alleys 6’min. in private corridors.
- Shade above ground level 70% of day by increasing the surrounding height walls by width of alley or patios.
- Allow direct light 30% of day for heat radiation in cold temperatures and daylighting.
- Provide shade zones at leace once every block for solar shelter between 11:00-2:00pm.
- Minimize solar reflection from indirect solar radiation in heavy-use areas.
- Integrate water features to increase temperature through evaporation.
- Increase shade along the direction of the prevailing wind to create wind tunnels.
- Provide movable partitions and sun shades to control solar heat gain in summer and winter.
- If new construction is in a complex, a courtyard must be provided.
- A rectangular courtyard with 4:5 ratio works best to provide enough privacy, daylighting and shading while absorbing enough heat for the cold months.
- Orient long facade along south facade for passive heat gain, with enough shading for the outdoor space.
- Provide largest area of openings for the entire dwelling towards the courtyard.
- Provide decidious trees, operable shading devices, as well as a central water feature to provide shading, humidity, and promote air circulation within the courtyard to create a micro-climate.
- Incorporate multi-level patios to provide shading for openings.

Part 3: Design Framework Parameters & Application

Chapter 5: Design Considerations & Weather Data

5.1: Thermal comfort

Understanding passive features found in cold-arid vernacular architecture provide a foundation to designing naturallly ventilated single-dwelling residences. However, there are characteristics that are unique to each location and have a direct relationship with the buidlings. To fully understand the application of each of the prototypes, design considerations should be analyzed in a precise location.

The following chapter aims to establish the design parameters unique to each site. Two total: a single-dwelling complex, and a single-dwelling dome/underground hut hybrid.

Thermal Comfort: Factors

Thermal comfort, as defined by ASHRAE is “The condition of mind which expresses satisfaction with the thermal environment” (ASHRAE 2013) [103] While there are factors of thermal comfort that may vary through the perception of each person, it is primarily affected and measured in three categories: Individual, Environmental, and Psychological. The combination of these three categories gauges the effect of thermal comfort at an individual level.

Individual factors can be further subdivided into the metabolic rate and clothing insulation. (Grondzik 2010)[104] Metabolism rate, measures in MET the rate at which the users generate heat, through metabolic processes, and is dependent on the amount of ac-

[103] (ASHRAE Standard 55 Thermal Environmental for Human Occupancy 2013)
[104] Grondzik, Walter, Alison Kwok, Benjamin Stein, and John Reynolds. 2010. Mechanical and Electrical Equipment for Buidlings, 11th Edition. New Jersey: John Wiley & Sons.

tivity, varying between rest, walking, activity, etc. For the purpose of this paper, it is assumed a fixed MET rate at rest: Seated at rest at 58.2 MET Units.

Activity	Metabolic Rate in Met Units[a]	Activity	Metabolic Rate in Met Units[a]
Resting		**Miscellaneous Work**	
Sleeping	0.7	Watch-repairing, seated	1.1
Reclining	0.8	Lifting/packing	1.2 to 2.4
Seated, reading	0.9	Garage work (e.g., replacing tires, raising cars by jack)	2.2 to 3.0
Office Work			
Seated, writing	1.0	**Vehicle Driving**	
Seated, typing or talking	1.2 to 1.4	Car	1.5
Seated, filing	1.2	Motorcycle	2.0
Standing, talking	1.2	Heavy vehicle	3.2
Drafting	1.1 to 1.3	Aircraft flying, routine	1.4
Miscellaneous office work	1.1 to 1.3	Instrument landing	1.8
Standing, filing	1.4	Combat flying	2.4
Walking (on Level Ground)		**Leisure Activities**	
2 mph (0.89 m/s)	2.0	Stream fishing	1.2 to 2.0
3 mph (1.34 m/s)	2.6	Golf, swinging and walking	1.4 to 2.6
4 mph (1.79 m/s)	3.8	Golf, swinging and with golf cart	1.4 to 1.8
Domestic Work		Dancing	2.4 to 4.4
Shopping	1.4 to 1.8	Calisthenics exercise	3.0 to 4.0
Cooking	1.6 to 2.0	Tennis, singles	3.6 to 4.6
House cleaning	2.0 to 3.4	Squash, singles	5.0 to 7.2
Washing by hand and ironing	2.0 to 3.6	Basketball, half court	5.0 to 7.6
Carpentry		Wrestling, competitive or intensive	7.0 to 8.7
Machine sawing, table	1.8 to 2.2		
Sawing by hand	4.0 to 4.8		
Planing by hand	5.6 to 6.4		

Figure 5.1 Metabolic Rate (MET) at different typical activities. [105]

The Clothing insulation, measured in CLO, labels the amount of additional coverage a person might have on their person, that can affect the overall comfort on the individual. The type or amount of clothing in a particular environment can provide the occupant the ability to adjust the varying climatic conditions in the natural environment. Due to the changing nature of the cold-arid climate being analyzed. There are two variable assumptions taken: Summer clothing of shorts and tee-shirt at 0.5 CLO unit, and Winter clothing of sweater and long pants at 1 CLO unit. (ASHRAE Standard 55 Thermal Environmental for Human Occupancy 2013) [106]

[105] Washington State University. 2016. "Human Comfort & Health Requirements." Courses: Comfort Health. March. Accessed January 2017.

[106] (ASHRAE Standard 55 Thermal Environmental for Human Occupancy 2013)

Men		Women	
Clothing	**clo**	**Clothing**	**clo**
Underwear		Underwear	
Sleeveless	0.06	Girdle	0.04
T-shirt	0.09	Bra and panties	0.05
Briefs	0.05	Half slip	0.13
Long underwear, upper	0.10	Full slip	0.19
Long underwear, lower	0.10	Long underwear, upper	0.10
		Long underwear, lower	0.10
Shirt		Blouse	
Light, short sleeve	0.14	Light, long sleeve	0.20
long sleeve	0.22	Heavy, long sleeve	0.29
Heavy, short sleeve	0.25	Dress, light	0.22
long sleeve	0.29	Dress, heavy	0.70
(Plus 5% for tie or turtleneck)			
Vest, light	0.15	Skirt, light	0.10
Vest, heavy	0.29	Skirt, heavy	0.22
Trousers, light	0.26	Slacks, light	0.10
Trousers, heavy	0.32	Slacks, heavy	0.44
		Sweater	
Sweater, light	0.20	Light, sleeveless	0.17
Sweater, heavy	0.37	Heavy, long sleeve	0.37
Jacket, light	0.22	Jacket, light	0.17
Jacket, heavy	0.49	Jacket, heavy	0.37
Socks		Stockings	
Ankle length, thin	0.03	Any length	0.01
thick	0.04	Panty hose	0.01
Knee high	0.10		
Shoes		Shoes	
Sandals	0.02	Sandals	0.02
Oxfords	0.04	Pumps	0.04
Boots	0.08	Boots	0.08
Hat and overcoat	2.00	Hat and overcoat	2.00

Figure 5.2 Clothing Rate (CLO) for Individual Types of Clothing.[107]

Environmental factors are quantifiable factors calculated in direct relationship to the environment in which the building is found. The four main categories to analyze are Air Temperature (°F), radiant temperature (°F), air velocity (ft/s), and relative humidity (%). Although they vary from place to place, they are the generally similar within the cold-arid climate. Air temperature, radiant temperature, and relative humidity can be controlled and manipulated. However, air velocity can not; it can only be channeled, received, or rejected. It is important to test these factors, primarily within the building envelope, due to its direct relationship with the external climatic conditions from the sun and wind, with diurnal and yearly fluctuations. They will guide the responsiveness to the seasons, and direct the occupant to control and optimize their indoor thermal comfort.

[107] Washington State University. 2016. "Human Comfort & Health Requirements." Courses: Comfort Health. March. Accessed January 2017.

Finally, in contrast to individual and environmental factors that are quantifiable, psychological factors are difficult to measure. Psychological factors include aesthetic characteristics such as color, texture, sound, light, movement, and aroma, as defined by ASHRAE. (Grondzik 2010) [108]. Due to the difficulty to quantifiably measure these factors, a special emphasis will be given to vegetation integration, daylighting in relationship to heat gain and space use, as well as color in relationship to heat absorption. Other factors, however, will be omitted from the prototype analysis.

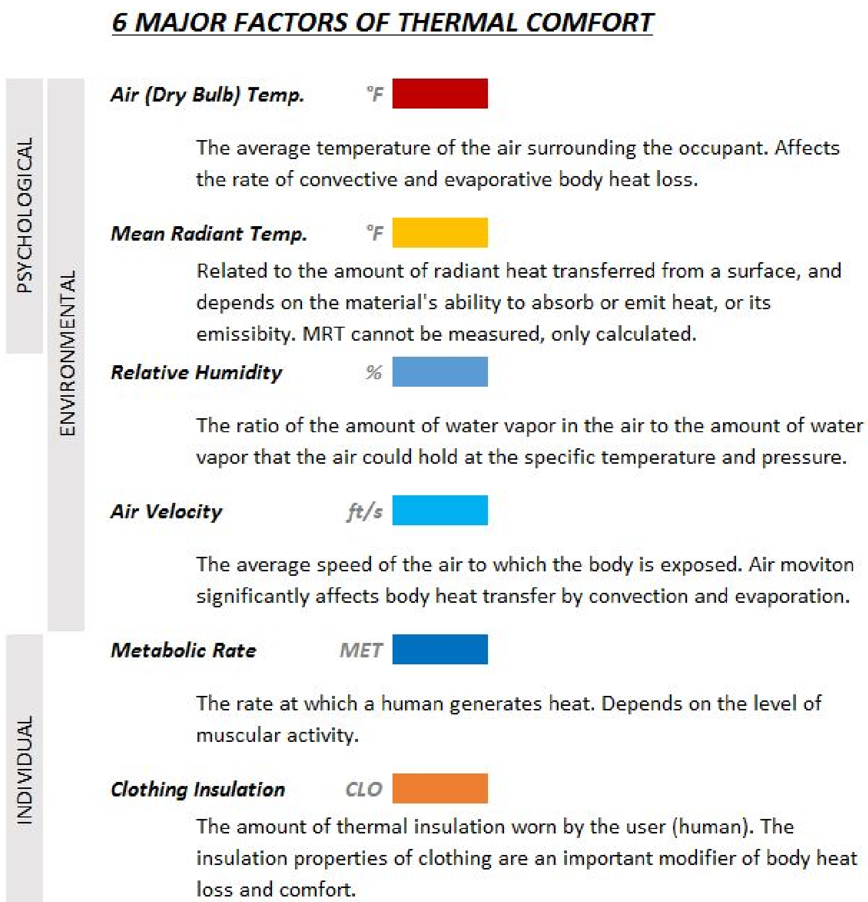

Figure 5.3 ASHRAE 6-Major determinants of Thermal comfort response. Redrawn by Author

[108] Grondzik, Walter, Alison Kwok, Benjamin Stein, and John Reynolds. 2010. Mechanical and Electrical Equipment for Buidlings, 11th Edition. New Jersey: John Wiley & Sons.

Thermal Comfort: Metric

ASHRAE Standard 55 recommends the use of the 7-point PMV/PPD thermal sensation scale to determine acceptable levels of thermal comfort. (ASHRAE Standard 55 Thermal Environmental for Human Occupancy 2013)[109] The scale measures PMV, or Predicted Mean Vote, and PPD, or Predicted Percentage of Dissatisfied. This model is one of the most widely used thermal comfort standards as it considers individual and environmental factors. The PMV model represents an average response of a large group of test subjects, with variations of comfort levels, are predicted and tested. The six main factors of thermal comfort discussed previously, are used as the main performance indicators of this model.

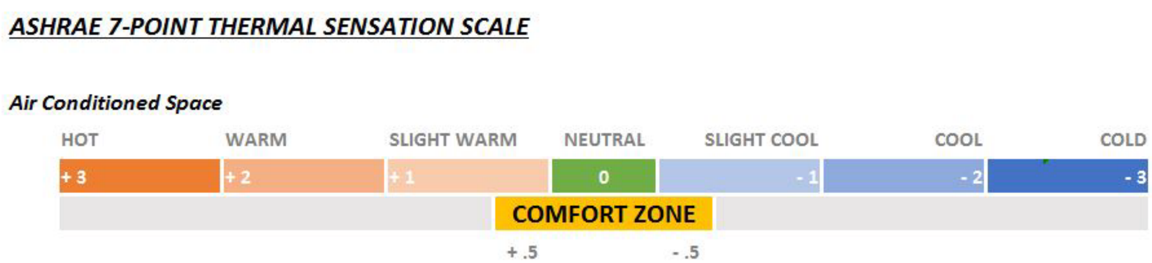

Figure 5.4 ASHRAE 7-Point Thermal Sensation Scale. Redrawn by author

The scale consists of 7-points of sensation, that are either considered comfortable or dissatisfied. The scale ranges between -3 to +3, with 0 considered neutral. Hourly conditions are calculated and determined in thermal sensation range of +3 hot, +2 warm, +1 slight warm, 0 neutral, -1 slight cool, -2 cool, and -3 cold.

The Predicted Percentage of Dissatisfied (PPD) is in direct correlation to the Predicted Mean Vote (PMV). As the PMV moves farther away from zero, in either direction, the PPD increases. Although zero is considered thermally neutral, the PMV measures a +

109 (ASHRAE Standard 55 Thermal Environmental for Human Occupancy 2013)

.5 and - .5 minimum range of PPD. In other words, even though neutral assumes a comfortable thermal sensation, there is approximately 5% of people that will find it slightly warm, and 5% of people that will find it slightly cool. (ASHRAE Standard 55 Thermal Environmental for Human Occupancy 2013) [110] Therefore, ASHRAE uses an acceptable thermal sensation scale that allows a maximum of 10% dissatisfied persons (PPD) in a typical mechanically conditioned space.

When designing for a naturally ventilated space, however, researchers have found that occupants in naturally conditioned spaces are more likely to go through a process of acclimatization. The concept relies on the adaptability of the user to slowly respond to changes in its environment. The study findings dictate that users aware that they are within a naturally ventilated space were found to be more tolerable to temperature swings that in those within mechanically conditioned spaces. (Brager 2001) [111] Their findings suggest that there are psychological factors in which the user's expectation to the variations of the climate led to an expanded thermal comfort zone (see figure below).

[110] (ASHRAE Standard 55 Thermal Environmental for Human Occupancy 2013)

[111] Brager, Gail, and Richard Dear. 2001. "limate, Comfort, and Natural Ventilation: A New Adaptive Comfort Standard for ASHRAE Standards 55." Center for Environmental Design Research: Center for the Built Environment.

ASHRAE 7-POINT THERMAL SENSATION SCALE

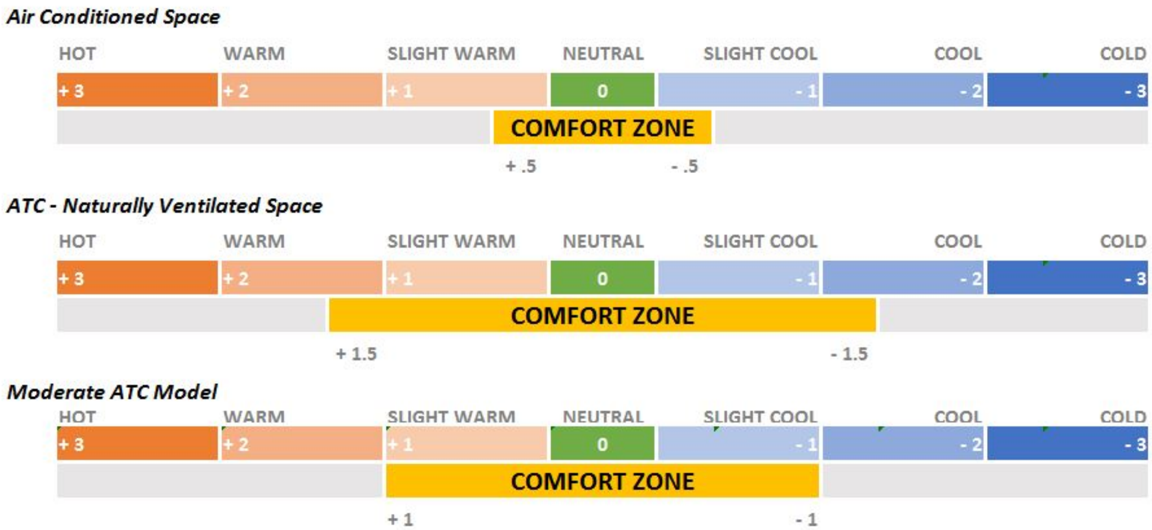

Figure 5.5 ASHRAE 7-Point Extended Thermal Sensation Scale. Redrawn by Author

As a response to these findings, the adaptive thermal comfort model was developed and implemented into the ASHRAE 55 standards. The adaptive thermal comfort model (ATC) compares the indoor temperature in relation to the outdoor air temperature to indicate its performance. (Linden 2008) [112] Though there is no large body of knowledge yet on how the Predicted Mean Vote model relates to naturally ventilated spaces, this project will use the available adaptive comfort thermal model to view the predicted differences between a naturally conditioned space vs. a mechanically conditioned one. The ATC model accounts for the psychological factors of users expectation, and links it to the PMV model, which accounts for individual and environmental factors, thus accounting for all 6-major factors of thermal comfort. (Linden 2008) [113] The ATC model also extends the comfort zone threshold from +/- .5 point, 10% predicted percentage of dissatisfied to +/- 1.5 (30% PPD), due to the users expectation values dis-

[112] Linden, Willemijne van der, Marcel Loomans, and Jan Hensen. 2008. Adaptive Thermal Comfort explained by PMV. The Netherlands: Eindhoven University of Technolory, Department of Architecture & Planning, Unit Building Physics and Systems.
[113] Ibid.

cussed above. (ASHRAE Standard 55 Thermal Environmental for Human Occupancy 2013) [114]

To compensate for the lack of knowledge available within the ATC, the PPD threshold is reduced to a Moderate ATC point of +/- 1 point, or 20% PPD. The intent of this is to establish a realistic level of comfort. Since the project is based on single-family residential units, it does not seem feasible to assume that 30% of the inhabitants will be uncomfortable. The idea is to design a passive residence, that does not influence the users to incorporate HVAC. Therefore, a moderate baseline will yield more realistic results.

5.2: Software Tools

All prototypes were modeled in Graphisoft ArchiCAD (Version 19) as well as Google Sketchup (Version 2016). The ArchiCAD models serve as the construction documents, as well as actual dimensions for the material thicknesses and elevations. Once the prototypes were completed, they were simplified into Google Sketchup for compatibility with the energy modeling software. The google Sketchup models served as a single-pane simplified model to be imported into two separate software for simulations on building performance.

Climate data was obtained from a typical Meteorological Year (TMY) weather data. Specifically: TMY3 Station Number 722700 WMO, El Paso International Airport, TX, USA. This file provided data sets of hourly values of several weather characteristics compiled for a 12-month period. The data was gathered and analyzed in Climate consultant (Version 6). It was used as a resource for graphical climate information, including psychrometric charts, wind rose diagrams, and solar path and radiation diagrams, etc.

[114] (ASHRAE Standard 55 Thermal Environmental for Human Occupancy 2013)

The simulations were initially conducted using Sefaira. As a plug in to sketchup, as well as a web-based stand alone, the software provides various simulation tools: Thermal simulations, solar and daylighting analysis, envelope, and HVAC usage.

The simulations were also conducted using Integrated Environmental Solutions Virtual environment software IES-VE (Version 2014). This software was used to conduct computational fluid dynamic modeling, CFD, to measure the accuracy of natural ventilation on the interior of the building.

Figure 5.6 Software Used throughout this project[115]

[115] (Image:, Logos of Sketchup, ArchiCAD, Sefaira, IES-VE, Climate Consultant 6 2017)

Chapter 6: Design Project

6.1: Site application factors

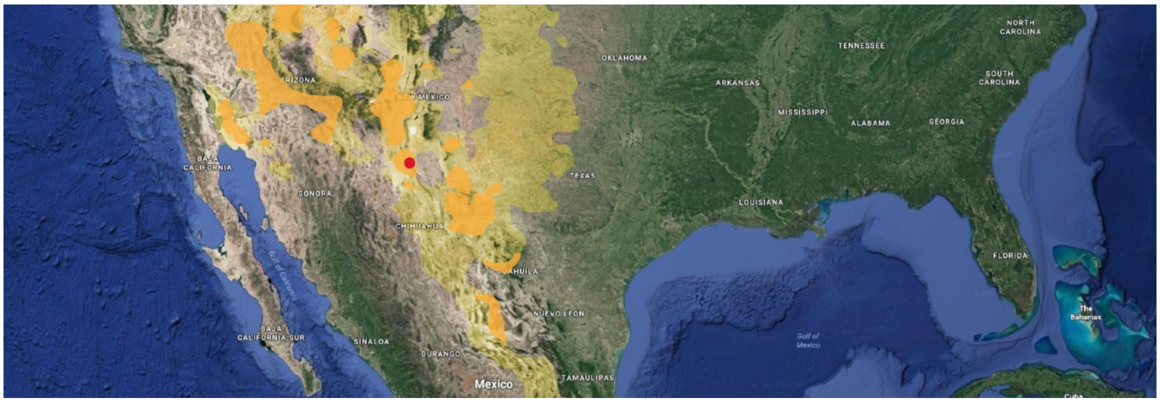

Figure 6.1 El Paso, TX (Red Dot) in relationship to N. American BWk & BSk deserts

Thermal comfort in the cold-arid desert climate zone (Koppen climate classification BWk and BSk can be difficult to achieve. (Koppen 2016)[116]. High thermal conditions, large diurnal contrast to Low thermal conditions, as well as lack of humidity, dust penetration, and wind velocity, play a major role in the overall thermal comfort of an individual. Usually, the direct relationship between outdoor air temperature and thermal comfort is considered the main design parameter. (Grondzik 2010)[117]

A study based in Iran, also classified as BWk, suggests that occupants in naturally ventilated buildings have a higher response threshold to changes in climate (Heidari 2002)[118]. Further studies found that users within naturally ventilated buildings were more

[116] Census, El Paso County. n.d.

[117] Grondzik, Walter, Alison Kwok, Benjamin Stein, and John Reynolds. 2010. Mechanical and Electrical Equipment for Buidlings, 11th Edition. New Jersey: John Wiley & Sons.

[118] Heidari, Shain, and Steve Sharples. 2002. "A comparative analysis of Shert-Term and Long-Term Thermal Comfort Surveys in Iran." Energy and Buidlings.

tolerable to temperature changes than users within air conditioned buildings. (Brager 2001)[119] The studies show a psychological behavior between the occupants, and their ability to adapt to the changing climate conditions through the use of clothing, controlling ventilation, and their behavior, expanding the thermal comfort threshold and zone.

Housing Market & Program

According to the 2016 Government Comprehensive Housing Market Analysis, El Paso, TX currently has an estimated HMA population of 860,700, with an estimated 282,500 households. Both statistics have been steadily increasing at about 1.5-2% annualy. The homeownership rate of the city is at 63.6%. Trends for ownership rather than rent have continually increased for the past decade due to the cheap availability of land in the suburbs, as well as the net in-migration from the City of Juarez, Mexico, the city's closest neighbor which accounts for city growth of 20% over the past decade. (Oduor 2016)[120]

					Average Annual Change					
					2000 to 2010		2010 to Current		Current to Forecast	
	2000	2010	Current	Forecast	Number	Rate (%)	Number	Rate (%)	Number	Rate (%)
Population										
El Paso HMA	679,622	800,647	831,900	860,700	12,100	1.7	7,825	1.0	9,600	1.1
Households										
El Paso HMA	210,022	256,557	272,300	282,500	4,650	2.0	3,925	1.5	3,400	1.2

Figure 6.2 Population & Household Trends in the El Paso HMA, 2000 to 2017 forecast

Although there is definitely a demand for housing in the city, most new construction occurs along the outskirts of the suburbs, with urban and sub-urban sprawl. The sprawl causes many traffic concerns and an average work commute of 15-40

[119] Brager, Gail, and Richard Dear. 2001. "limate, Comfort, and Natural Ventilation: A New Adaptive Comfort Standard for ASHRAE Standards 55." Center for Environmental Design Research: Center for the Built Environment.

[120] Oduor, Elizabeth. 2016. Comprehensive Housing Market Analysis. Census Report, El Paso, TX: US Department of Housing & Urban Development.

minutes (E. P. Census 2014)[121].

	Median Income ($)			Average Annual Change (%)	
	1999	2009	2012	1999 to 2009	2009 to 2012
Median Family Income	34,100	39,700	41,700	1.5	1.7
Median household income	31,051	36,015	40,345	1.5	3.9

Figure 6.3 Median Income in the El Paso HMA, 1999, 2009, and 2012[122]

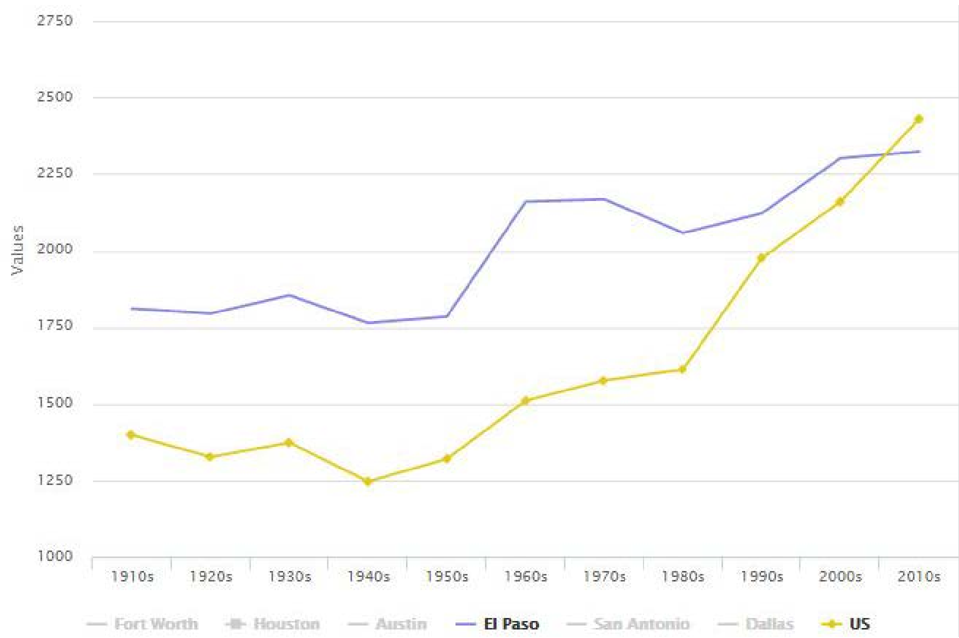

Figure 6.4 Average Single-Family Home size in TX compared to the USA[123]

As seen in the figure above, the trend for larger housing is not localized to Texas. For a single-family residence, for a family of 5 (Two heads of household, three children), the square footage has steadily increased since the 1940's. In the United States, the average size of housing has nearly doubled from 1,250 sf to 2,400 sf in 2010. (Oduor

[121] Census, El Paso County. n.d.

[122] Oduor, Elizabeth. 2016. Comprehensive Housing Market Analysis. Census Report, El Paso, TX: US Department of Housing & Urban Development.

[123] Ibid

2016)[124] While El Paso had a tendency for larger than average houses since the 1900's, the need for larger buildings has increased at a slower rate than the average US and has caught up to the country's average.

A question arises when examining the city's median family income, as well as the ever-growing sizes of houses. Although there are plenty of housing options available, for a wide income range, there are limitations to what money can buy. At a median new-construction home price of $160,000 in El Paso, the median household can't affort the prices and has to either keep renting or move to even farther suburbs to get their desired square footage. However, are there any households that would rather have a smaller footprint in exchange to being within the urban context.

Part of the answer is to respond with a small(er) footprint, that can exchange square footage price for land, and fit within existing empty lots in the urban center, as well as having a well design footprint that can provide a "home" to any household, regardless of their income or land. The purpose of this project is not to provide for low-income housing, but to create a framework from which people can expand, that is accessible to all income levels in the city of El Paso.

Optimization of residential environment is aimed to have thermal comfort conditions. Through considerations of human sensible and latent heat loads, the metabolic heat gain of small spaces can be determined as the minimal area per person to provide optimal space design.

According to the engineering toolbox, the ideal area per per person is to provide 200-600 sf. per person in a residential condition. (Engineering ToolBox n.d.)[125] The first person requires 600 sf, with 200 sf. per additional user, up to 5 users.

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[124] Oduor, Elizabeth. 2016. Comprehensive Housing Market Analysis. Census Report, El Paso, TX: US Department of Housing & Urban Development.

While the average family size in the US is only at 2.54 per household, the typical household size in El Paso is well above average, at 3.54. (U. Census 2014)[126] Therefore, this project is focused on optimization of residential environment for 3-4 persons comfortably. Ideally designed for a couple with two children or a single head of house with two children. Space dimensions are kept similar in both prototypes, with emphasis on space given to shared space, as well as provided additional exterior living space for area compensation to rooms that do not comply with adaptive comfort standards in either hot or cold season.

[125] (Engineering ToolBox n.d.)
[126] Census, US. 2014. "Government US Census."

Area Calculations & Program

Prototype 1

Sub-Urban

sf per user		Interior	Exterior
	Adult	600	
	Adult	200	
	Child	200	
	Child	100	100
	Seasonal Use		250
		1,100	*350*
			1,450 sf

Program		Interior	Exterior
	Living Area	231	
	Kitchen	112	
	Corridor	271	
	Bedroom 1	161	
	Bedroom 2	100	
	Bedroom 3	100	
	Restroom 1	43	
	Restroom 2	60	
	Outdoor living		155
	Open Courtyard		210
		1,078	*365*
			1,443 sf

Prototype 2

Urban

	Interior	Exterior
Adult	600	
Child	200	
Child	200	
*future expansion		200
Seasonal Use		250
	1,000	*450*
		1,450 sf

Program	Interior	Exterior
Living Area	228	
Kitchen	112	
Corridor	231	
Bedroom 1	156	
Bedroom 2	100	
Bedroom 3	100	
Restroom 1	42	
Restroom 2	40	
Outdoor living		90
Open Courtyard		388
	1,009	*478*
		1,487 sf

Figure 6.5 Area calculations & program

The chart presents the breakdown of square footage calculations for the expected users, as well as determinants for indoor vs. outdoor space.

Location Analysis

Figure 6.6 EL Paso, TX, located along border of United States of America & Mexico

The location chosen for the Prototype application is the city of El Paso, TX, United States of America. The climate is classified as cold-arid desert, that ranges from cold-dry, moderate, to hot-dry throughout the year. The average temperature, humidity, wind, and illuminance is further depicted in the following chart.

For the purpose of this project, information will be derived only from the monthly averages broken down into hourly data, and not extreme weather conditions, such as record breaking heat, flash floods, wind storms, etc.

WEATHER DATA SUMMARY - Monthly Average

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Dry-Bulb Temperature	F	46	50	54	66	74	82	81	79	74	64	52	44
Max. Temperature	F	58	63	70	79	88	96	95	92	88	78	66	57
Low Temperature	F	33	37	43	51	60	68	71	70	63	52	40	33
Diurnal Temperature	F	25	26	27	28	28	28	24	22	25	26	26	24
Ground Temperature	F	58	53	51	51	56	62	68	74	76	75	71	65
Humidity	%	48	38	31	25	27	29	49	45	51	53	44	46
Precipitation	inch	0.39	0.47	0.28	0.24	0.47	0.94	1.54	2.01	1.5	0.59	0.47	0.79
Snowfall	inch	1	1	0	1	0	0	0	0	0	0	1	3
Wind Speed	mph	7	8	1	10	11	9	7	7	4	7	7	6
Wind Direction	deg	0	0	270	250	240	140	140	90	130	0	10	10
Direct Illumination	fc/hr	464	4864	4999	5356	5237	5392	4494	4517	5239	4986	5208	4536

Figure 6.7 Average monthly environmental conditions based on TMY3 file. Redrawn by Author

Average high temperatures range from 88-96 °F during summer months (May to September) and 57-79 °F during winter months (October to April). Average low temperature ranges from 60-71 °F during summer and 52-33 °F during winter. Diurnal temperature ranges from 24-28 °F throughout the year. Although humidity is present throughout the year from an average of 25-53%, please note that due to evapotranspiration, where the level of evaporation is double the level or precipitation, the climate remains arid throughout the year. Leading in turn to an average of less than 10” per year. Wind speed averages annually between 1-11 mph, or 1.4-16.2 ft/s, with the strongest winds coming in from the S-SW.

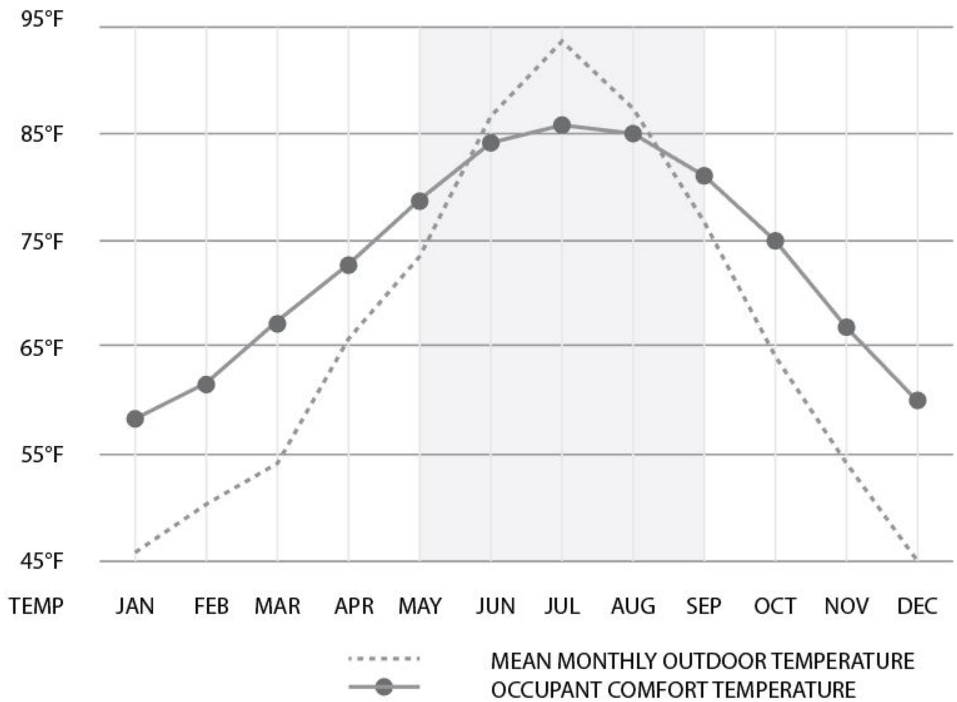


Figure 6.8 Mean monthly Outdoor & Occupant comfort temperature for El Paso, TX

The weather data provided valuable insight into the use of vernacular components. The function of different components applied into the prototypes function very differently in contrasting seasons. While a component is designed ideally to bring ventilation into the building, for example, it’s efficiency to cool the building down can also hinder the efficiency of the building during the cold months. This is something that has to be addressed in depth. To aid with the accuracy of the energy modeling simulations, the year is divided into two categories: the 5-Hot months from May to September, and the 7-Cold months from October through April. The Yearly Climatic Division chart below presents the percentage of time within the comfort level range, shown in green (69-81 °F) uncomfortably hot percentage of time shown in orange gradient (81-100 °F), as well as uncomfortably cold percentage of time shown in blue gradient (32-69 °F). The gradient is directly correlated with the ASHRAE 7-point thermal sensation scale.

Figure 6.9 Yearly climatic division based on Weather Data Summary

The following psychrometric charts illustrate the comfort zone applicable to the site of El Paso Texas, with the expanded thermal comfort zone as per ASHRAE 55 Adaptive Comfort Model, to include an introductory acceptability limits of natural ventilation, at a 20% predicted percentage of Dissatisfaction (PPD). The first chart represents an average year time-lapse, indicating only 26% of the time lies within acceptable comfort standards. The Cold-month psychrometric chart notes only a 14% of comfort range without heating, and the Hot-month psychrometric chart notes 37% thermal comfort.

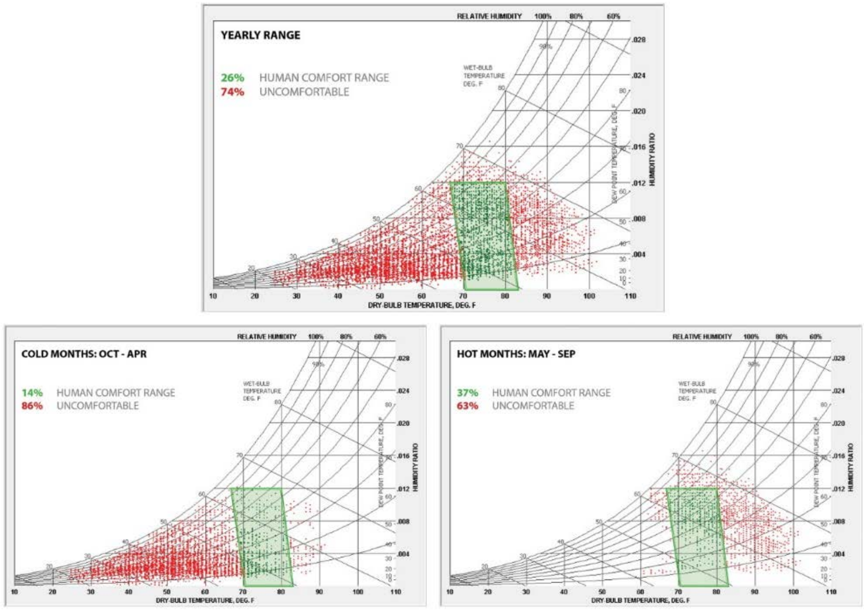
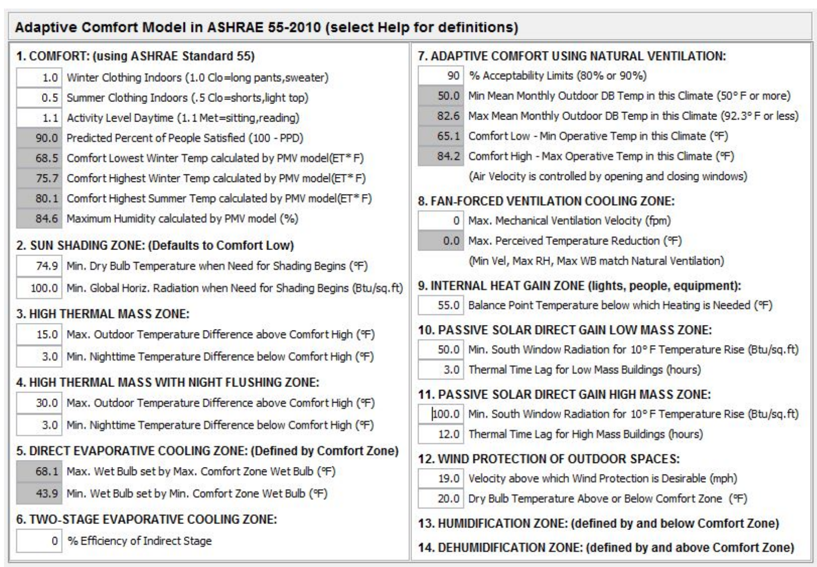


Figure 6.10 Annual Psychrometric chart for Naturally Ventilated Residences [127]



Adaptive Comfort Model in ASHRAE 55-2010 (select Help for definitions)

1. COMFORT: (using ASHRAE Standard 55)
1.0 Winter Clothing Indoors (1.0 Clo=long pants,sweater)
0.5 Summer Clothing Indoors (.5 Clo=shorts,light top)
1.1 Activity Level Daytime (1.1 Met=sitting,reading)
90.0 Predicted Percent of People Satisfied (100 - PPD)
68.5 Comfort Lowest Winter Temp calculated by PMV model(ET* F)
75.7 Comfort Highest Winter Temp calculated by PMV model(ET* F)
80.1 Comfort Highest Summer Temp calculated by PMV model(ET* F)
84.6 Maximum Humidity calculated by PMV model (%)

2. SUN SHADING ZONE: (Defaults to Comfort Low)
74.9 Min. Dry Bulb Temperature when Need for Shading Begins (°F)
100.0 Min. Global Horiz. Radiation when Need for Shading Begins (Btu/sq.ft)

3. HIGH THERMAL MASS ZONE:
15.0 Max. Outdoor Temperature Difference above Comfort High (°F)
3.0 Min. Nighttime Temperature Difference below Comfort High (°F)

4. HIGH THERMAL MASS WITH NIGHT FLUSHING ZONE:
30.0 Max. Outdoor Temperature Difference above Comfort High (°F)
3.0 Min. Nighttime Temperature Difference below Comfort High (°F)

5. DIRECT EVAPORATIVE COOLING ZONE: (Defined by Comfort Zone)
68.1 Max. Wet Bulb set by Max. Comfort Zone Wet Bulb (°F)
43.9 Min. Wet Bulb set by Min. Comfort Zone Wet Bulb (°F)

6. TWO-STAGE EVAPORATIVE COOLING ZONE:
0 % Efficiency of Indirect Stage

7. ADAPTIVE COMFORT USING NATURAL VENTILATION:
90 % Acceptability Limits (80% or 90%)
50.0 Min Mean Monthly Outdoor DB Temp in this Climate (50° F or more)
82.6 Max Mean Monthly Outdoor DB Temp in this Climate (92.3° F or less)
65.1 Comfort Low - Min Operative Temp in this Climate (°F)
84.2 Comfort High - Max Operative Temp in this Climate (°F)
(Air Velocity is controlled by opening and closing windows)

8. FAN-FORCED VENTILATION COOLING ZONE:
0 Max. Mechanical Ventilation Velocity (fpm)
0.0 Max. Perceived Temperature Reduction (°F)
(Min Vel, Max RH, Max WB match Natural Ventilation)

9. INTERNAL HEAT GAIN ZONE (lights, people, equipment):
55.0 Balance Point Temperature below which Heating is Needed (°F)

10. PASSIVE SOLAR DIRECT GAIN LOW MASS ZONE:
50.0 Min. South Window Radiation for 10° F Temperature Rise (Btu/sq.ft)
3.0 Thermal Time Lag for Low Mass Buildings (hours)

11. PASSIVE SOLAR DIRECT GAIN HIGH MASS ZONE:
100.0 Min. South Window Radiation for 10° F Temperature Rise (Btu/sq.ft)
12.0 Thermal Time Lag for High Mass Buildings (hours)

12. WIND PROTECTION OF OUTDOOR SPACES:
19.0 Velocity above which Wind Protection is Desirable (mph)
20.0 Dry Bulb Temperature Above or Below Comfort Zone (°F)

13. HUMIDIFICATION ZONE: (defined by and below Comfort Zone)

14. DEHUMIDIFICATION ZONE: (defined by and above Comfort Zone)

Figure 6.11 Adaptive Comfort model inputs for ASHRAE 55 – 90% adaptability limits and 0% air conditioning use. (Climate Consultant 6.0 2016)[128]

[127] (Climate Consultant 6.0 2016)
[128] Ibid

6.2: Massing model simulation – prototype inputs

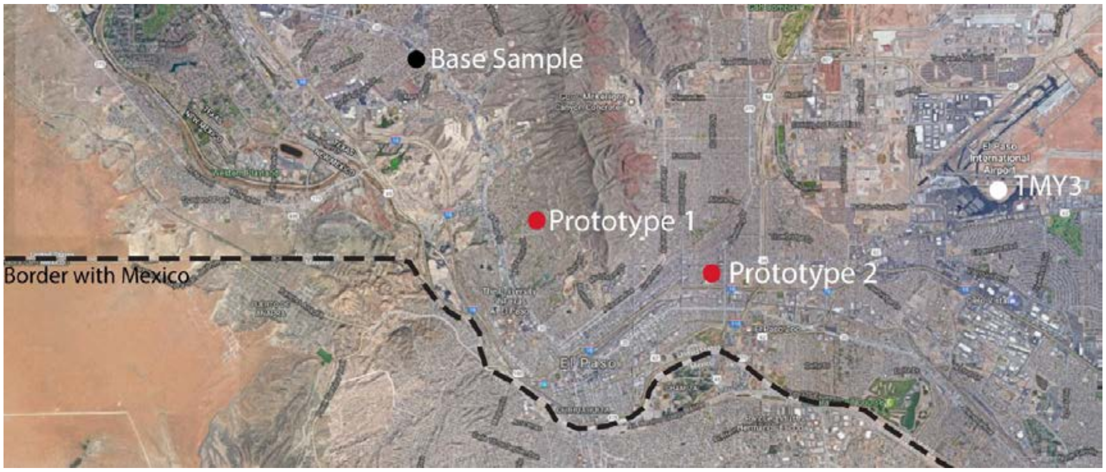


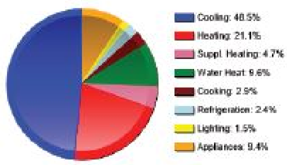
Figure 6.12 Prototype locations within a 10-mi. radius

The following prototypes were selected within two sites in the El Paso, area. It should be noted that weather data was only available upon a single point, the El Paso International Airport. Location of TMY3 noted in map above. This rendered the geometry of each model a decision based on climate per season rather than by location.

Base Sample – Typical Construction

A base sample was generated from an existing residence located within the context of the project, as a baseline comparison of the typical new-residential construction: wood stud, single pane tight window. The house type is a single story, 1,500 sf. standalone house built in 1969. The house has three bedrooms, two living spaces, a kitchen, and a garage. The house shape is a square with no relationship to cardinal orientation. Central air natural gas cooling, and natural gas heating with comfort settings set at 74^{o}F heating, and 75^{o}F cooling, according to the local electric company and Home and energy calculator comprehensive report. (Electrc 2016)[129]

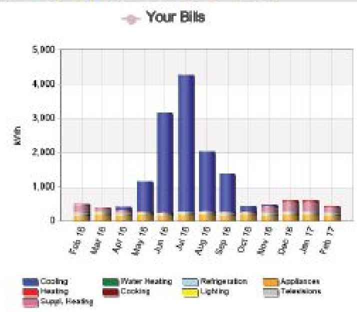
Estimated Annual Total Cost

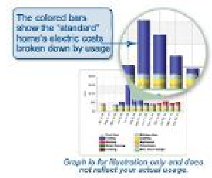


Estimated Annual Total Cost

	Gas	Electric	Total Cost
Cooling	$0	$1,205	$1,205
Heating	$499	$26	$525
Supplemental Heating	$0	$116	$116
Refrigerators/Freezers	$0	$59	$59
Lighting	$0	$37	$37
Cooking	$73	$0	$73
Water Heating	$238	$0	$238
Dishwasher	$0	$8	$8
Clothes Washer	$0	$6	$6
Clothes Dryer	$0	$108	$108
Other Appliance	$0	$110	$110
Elec. Base Charge	$0	$60	$60
Fuel Base Charge	$96	$0	$96
Total Per Year	$906	$1,735	$2,641
Average Per Month	$75	$145	$220

Estimated Monthly Electric Use





Month	Avg. Temp	Days	Cooling	Heating	Suppl. Heating	Refrig.	Lights	Dish-washer	Clothes Washer	Clothes Dryer	Other Appliance	Total
Feb 17	56.4 F	28	0	38	167	43	27	6	5	79	80	444
Jan 17	48.8 F	31	0	65	287	48	30	6	5	87	89	617
Dec 16	49.3 F	31	0	64	281	48	30	6	5	87	89	610
Nov 16	57.5 F	30	2	38	167	46	29	6	5	84	86	463
Oct 16	71.5 F	31	171	2	11	48	30	6	5	87	89	448
Sep 16	76.5 F	30	1,127	2	8	46	29	6	5	84	86	1,393
Aug 16	77.4 F	31	1,725	7	30	48	30	6	5	87	89	2,027
Jul 16	89.4 F	31	3,997	0	0	48	30	6	5	87	89	4,262
Jun 16	85.0 F	30	2,895	0	0	46	29	6	5	84	86	3,152
May 16	74.6 F	31	886	4	16	48	30	6	5	87	89	1,171
Apr 16	66.8 F	30	91	13	58	46	29	6	5	84	86	418
Mar 16	62.8 F	31	0	23	100	48	30	6	5	87	89	387
Feb 16	53.4 F	29	0	48	211	45	28	6	5	81	83	507
Annual Total		365	10,894	254	1,125	561	348	74	61	1,025	1,048	15,391
Monthly Average		30	908	21	94	47	29	6	5	85	87	1,283

Figure 6.13 Base Sample – Estimated annual total cost & Estimated monthly electric use [130]

[129] Electrc, E.P. 2016. "Home energy Calculator Comprehensive Report." Home Energy Suite. Accessed February 27, 2017. https://www.epelectric.com/tx/residential/tools-tips-and-calculators.

[130] Ibid

Orientation relative to sun and wind

High solar radiation and wind speed impacts are determined per prototype in consideration to the maximum need for heating or cooling. It is important to note that according to the psychrometric charts, a large portion of the year does not currently fit within the ASHRAE comfort zone parameters, particularly during the cold months.

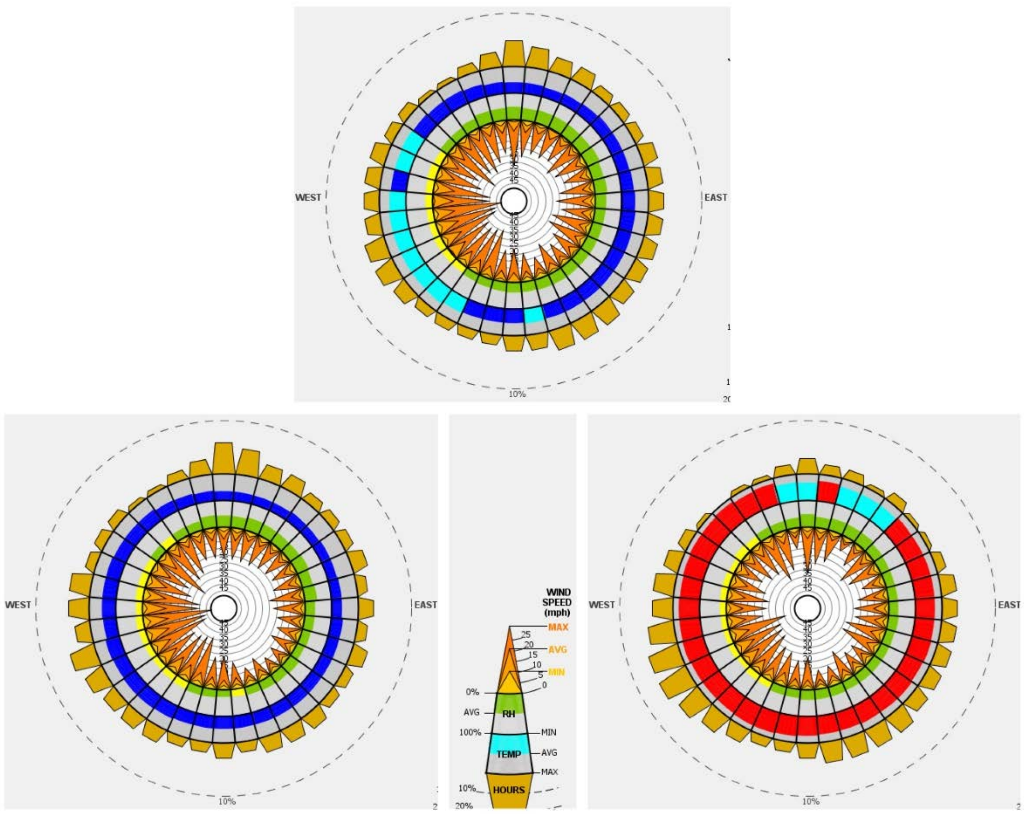


Figure 6.14 Annual, Hot & Cold months, Wind rose diagram[131]

Prevailing winds are a critical part of consideration for this project. Due to thermal discomfort being vastly greater for being too cold rather than to hot, limiting natural ventilation during the cold months played a key part into consideration. A series of iterations calculated the optimum orientation relative to wind and sun. The prevailing wind

[131] (Climate Consultant 6.0 2016)

direction selected for both prototypes was based on the increased need for ventilation from May – September. On average, the prevailing winds from the west are the most comfortable throughout the year. However, the prototypes were directed towards the comfortable May to September the prevailing winds from the NE to receive cooler breezes, rather than stronger speeds.

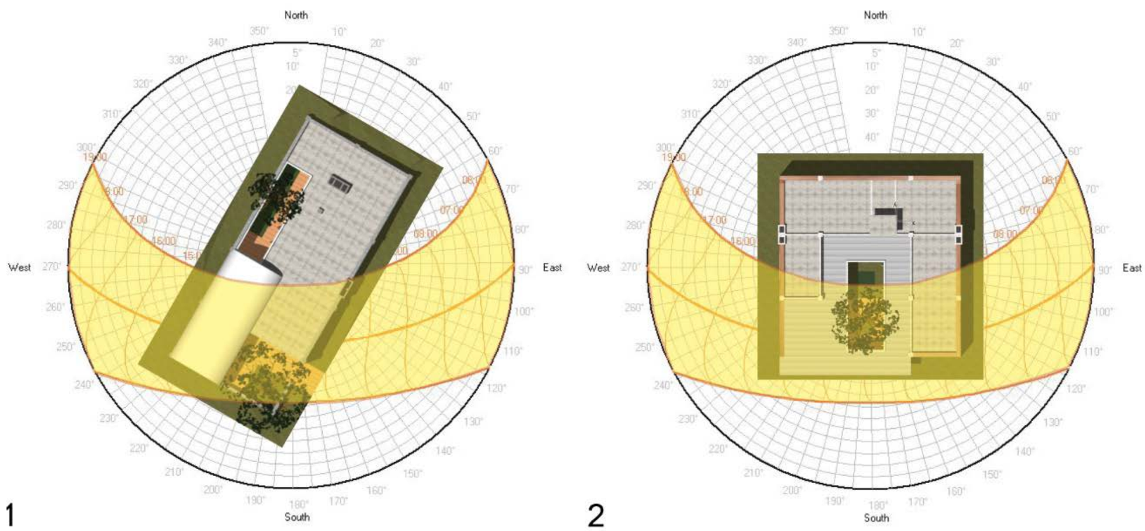


Figure 6.15 Annual Sun Path in relationship to prototypes 1 & 2

Solar considerations were considered with priority for winter heating. Traditional vernacular architecture arranges the long face of the building with an east west direction, to minimize solar heat gain during sunrise and sunset, and to apply optimal shading along the south façade. The prototypes were also designed with flat roofs, to increase solar heat gain during winter.

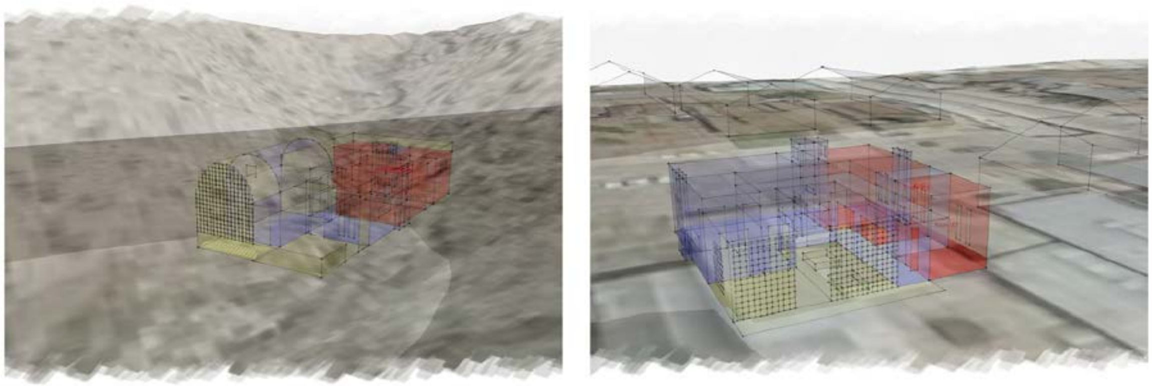

Prototype 1 Prototype 2

Figure 6.16 Snapshot of model inputs within contextual environment

Three major differences can be noted within the contextual environment. The major differences that are quantified are the overall rotation angle of the sites. Prototype 1 is rotated at 30°N, while the Prototype 2 does not have a rotation angle. The second difference was the altitude and wind direction differentials. Prototype 1 is nestled within the mountains at a, changing the direction in which air flows through the site perpendicular to the mountain range. Finally, prototype was selected in a sub-urban barren landscape with no vegetation, shading, or surrounding buildings. Prototype 2, on the other hand, has several buildings and trees surrounding that impact its direct access to wind direction and solar efficiency.

6.3: Massing model simulation – prototype results

The design process consisted of developing a set of simple guidelines mimicking global desert applications. The lessons learned and component matrix led to a simple step-by-step of components into the schematic design phase. This section aims to portray construction documents and diagrammatic thermal comfort results. The results were then contrasted with the base sample, to analyze the efficiency of the prototypes with a modern application.

Prototype 1 – Mountainside Sub-Urban

Figure 6.17 Prototype 1 – 1020 Cerro Azul Dr., El Paso, TX 79902

This prototype was designed as a hybrid of the hut and dome archetypes found within the cold-arid desert vernacular. 4 main characteristics were directly extrapolated from the case studies: Geothermal temperature gradient effect, Single membrane wall to roof transition, Indirect natural daylighting & thermal attic. The following graphic depicts the massing process depicting the primary guidelines used from the component matrix.

1. Single family residence of 3: 1 adults & 2 kids with 600 sf. allocated for the

first person, including shared space calculations. 200 sf each additional person, and 300 sf annual/diurnal space.

2. Interior and exterior space included in total construction areas. 1,400 sf livable area: 1,000 enclosed, 400 outdoor spaces equaling 1,600 sf total construction including uncovered lanai.
3. Interior courtyard along Northeast axis and open courtyard. Summer microclimatic effects cool air pools within central.
4. Separation of summer spaces and winter spaces. Summer spaces include shared spaces; Winter spaces include bedrooms.
5. Geothermal insulation underground. Energy storage and temperature exchange between day and night – 12 hours. Provides an escape from overwhelming heat days through inner courtyard & southern overhangs.
6. Interior courtyard and open courtyard provide buffer between solar heat gain within the occupable spaces. Channel cooler air through integrated ventilation shafts.
7. Promote ventilation and access to prevalent winds, while protecting against hot summer winds. Courtyard becomes main provider for natural ventilation and daylighting; exterior facing openings are limited. Roof vaulting promotes cooler air ventilation, as well as dissipates direct solar heat gain hours.
8. Deciduous vegetation to promote and control air movement in the summer, and allow direct heat in the winter. Shading walls for control within the courtyard to limit heat gain and shaded outdoor space to extend usable square footage and protect from south summer heat gain.
9. Permeable enclosure surrounding the courtyard to protect against solar irradiation and promote ventilation. Gas powered central hearth in proximity to circulation spaces. Additional fireplace in each space.

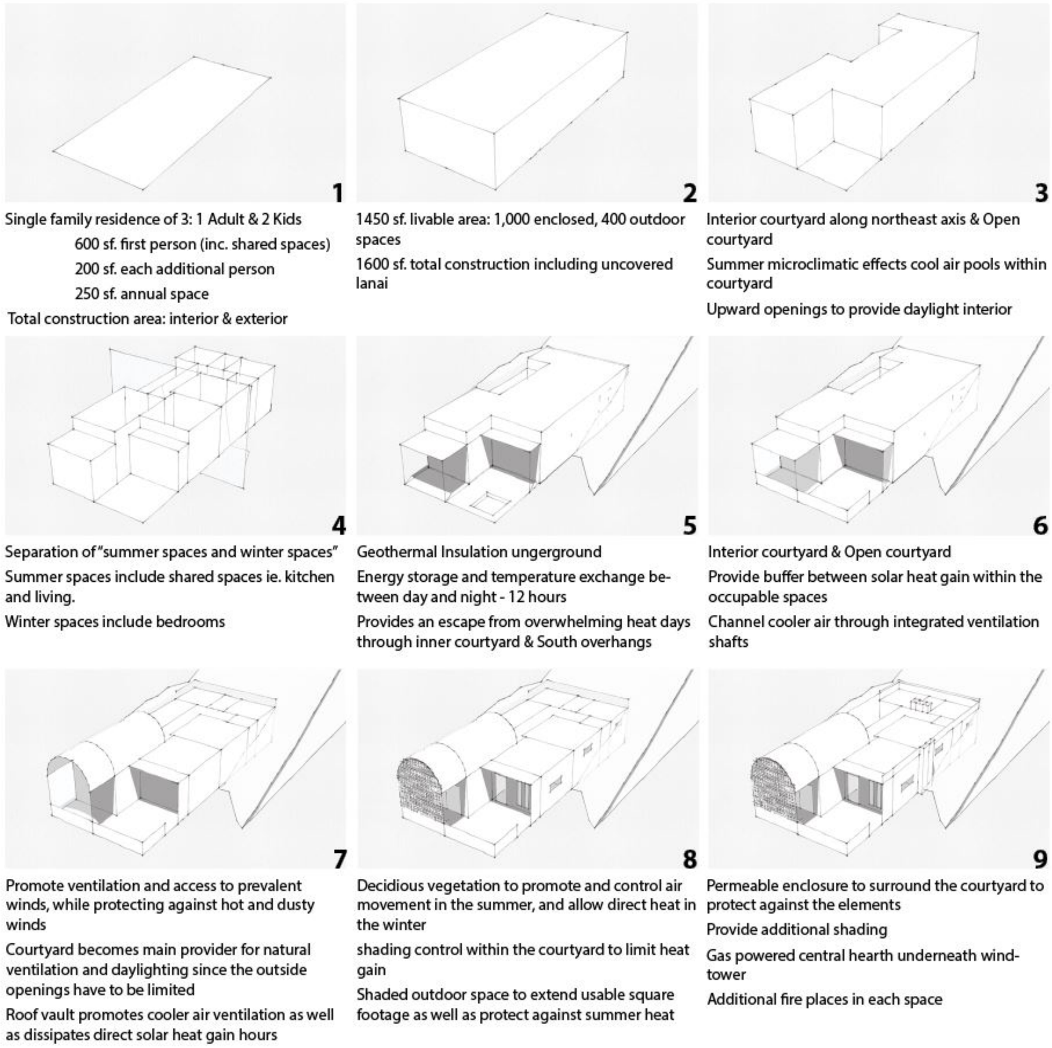


Figure 6.18 – P1 – Step-by-step breakdown of vernacular components

Figure 6.19 – scale:3/32” - P1 Passive lighting, heating, and cooling systems breakdown

Anticipated passive lighting, heating and cooling systems:

1. Daylighting focused on shared spaces. Skylights incorporated in private spaces. Interior courtyard used for indirect lighting to back spaces.
2. Building inset into mountainside to apply geothermal heating strategies to ½ of building walls. Small interior chimneys provided at private spaces. Hearth located in shared corridor. Solar heat gain anticipated at elevated vault and interior courtyard.

3. Primary cooling strategy implemented at vault through Bernoulli effect. All window openings only wooden louvers, no glass. Doors along interior courtyard also louvered. Vegetation for Air humidification and shading.

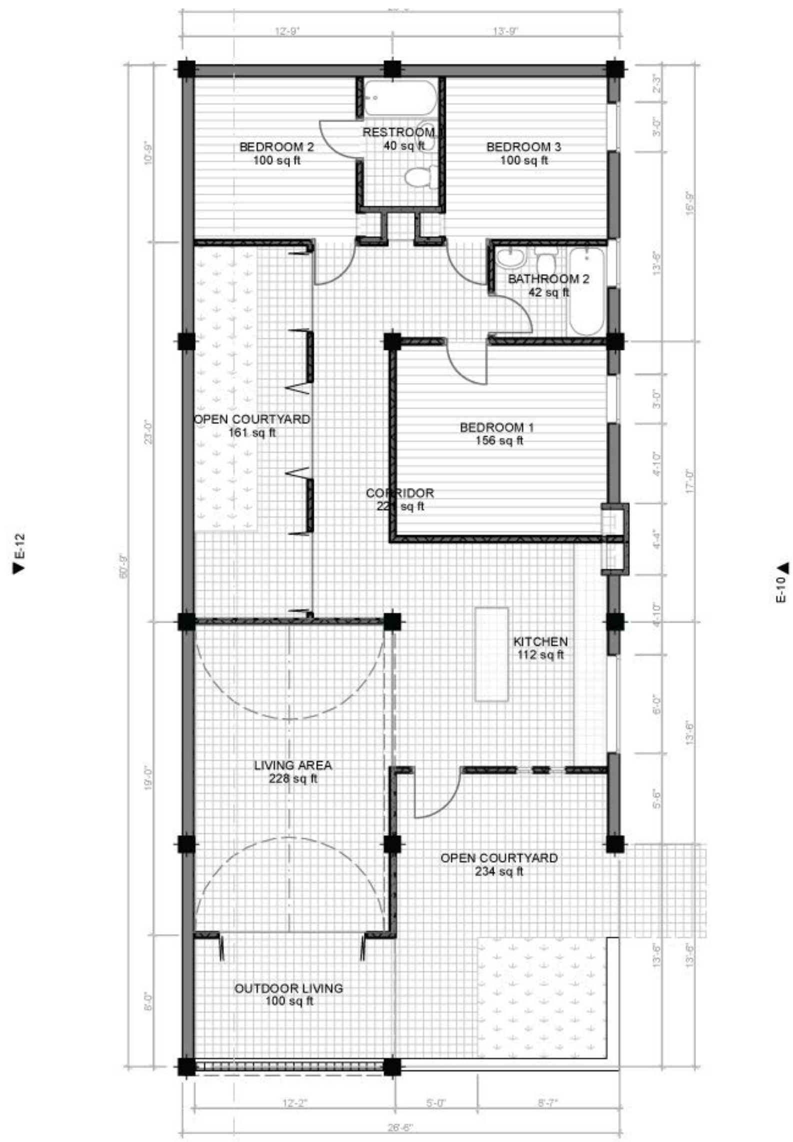


Figure 6.20 – scale:3/32” – P1 Floor Plan

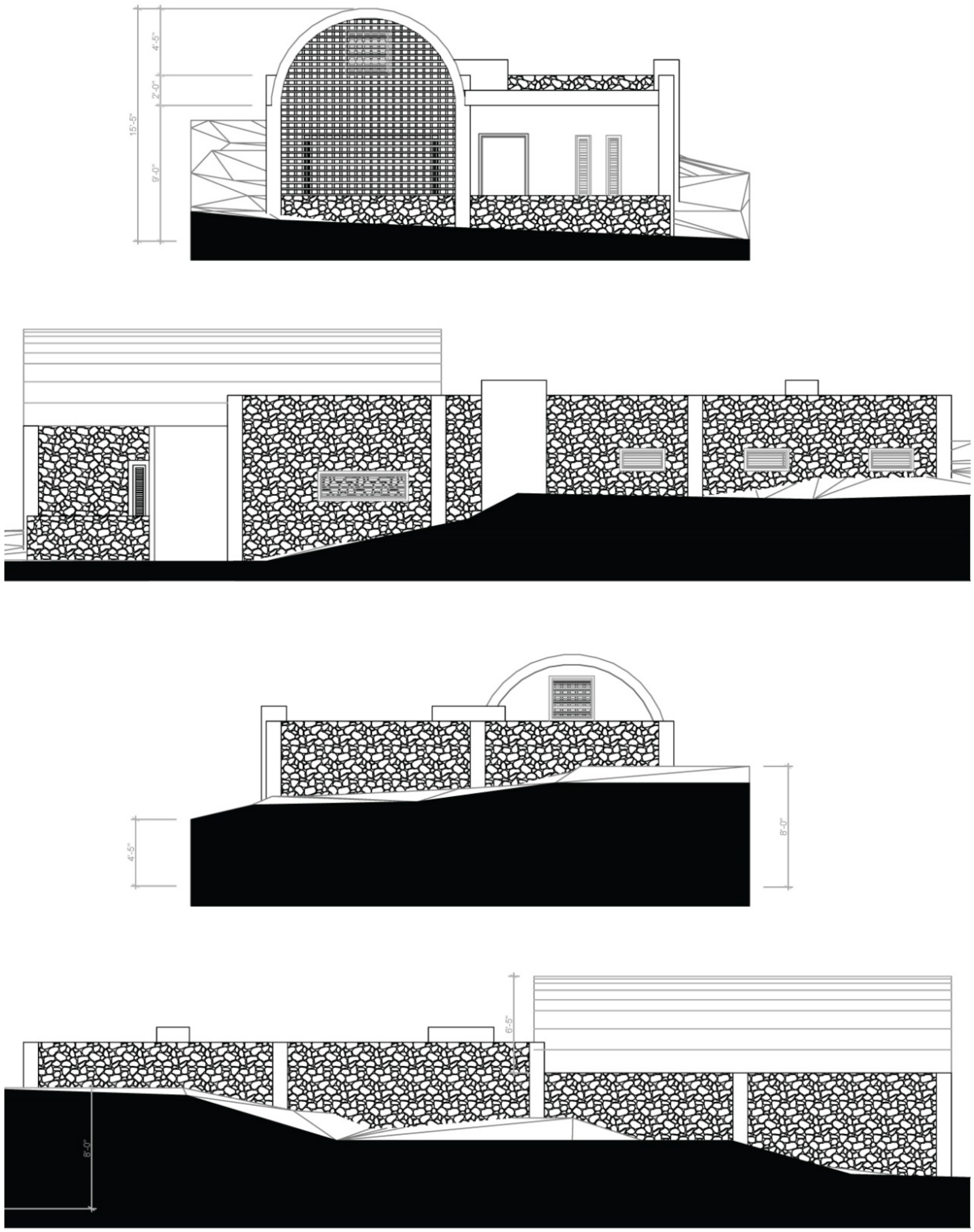


Figure 6.21 – scale:3/32" - P1 Elevations

Figure 6.22 – P2 Rendered section

Figure 6.23 - P2 Isometric rendering

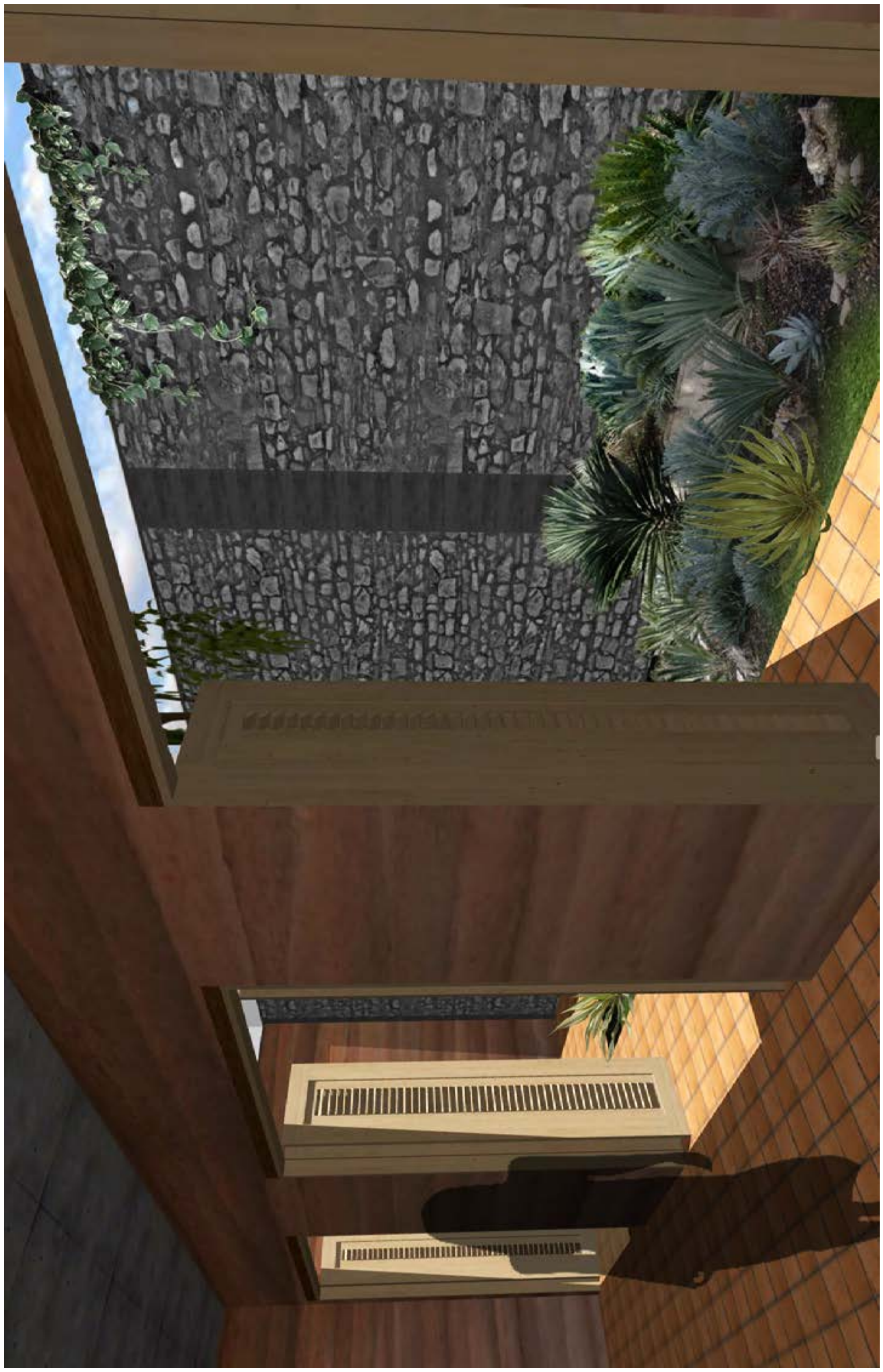


Figure 6.24 - P2 Interior rendering at open courtyard

Prototype 2 –Urban Courtyard

Figure 6.25 Prototype 2 – 3924 Clifton Ave, El Paso, TX 79903

This prototype was designed as a hybrid of the complex and hut archetypes found within the cold-arid desert vernacular. 4 main characteristics were directly extrapolated from the case studies: Centralized courtyard, Humidification of air through water & vegetation, Stack ventilation techniques & High Thermal massing. The following graphic depicts the massing process depicting the primary guidelines used from the component matrix.

10. Single family residence of 4: 2 adults & 2 kids with 600 sf. allocated for the first person, including shared space calculations. 200 sf each additional person, and 250 sf annual/diurnal space.
11. Interior and exterior space included in total construction areas. 1,450 sf livable area: 1,100 enclosed, 350 outdoor spaces equaling 1,600 sf total construction including uncovered lanai.
12. Open courtyard along east/west axis Summer microclimatic effects cool air pools within courtyard. Inward openings to minimize solar radiation.

13. Arcades surrounding courtyard provide buffer between solar heat gain within the couplable spaces. Also, channel cooler air through integrated ventilation shafts.
14. Outdoor space naturally ventilated and shaded by building and central vegetation. Provides an escape from overwhelming heat days using a centralized wind tower. Promote ventilation and access to prevalent winds, while protecting against hot and dusty eastern winds.
15. Separation of summer spaces and winter spaces. Summer spaces include shared spaces. Winter spaces include bedrooms. Bathrooms are excluded from location analysis.
16. Courtyard becomes main provider for natural ventilation and daylighting. Exterior facing openings are limited to 10-15% of face area. Shading control within the courtyard to limit heat gain.
17. Central pool to evaporate water and increase the temperature of the surrounding air. Deciduous vegetation to promote and control air movement in the summer, and allow direct heat in the winter.
18. Permeable enclosure surrounding courtyard to provide protection against the elements, additional thermal mass shading, and enclosed "pooling" area for cool air to gather.
19. High heat capacity thermal mass roof to provide sufficient time lag. Energy storage and temperature exchange between day and night – 12 hrs. Extend beyond ext. south walls for shading & slope inward for water catchment.
20. Thick thermal walls for heat balance. Time lag requirements for walls= East – 0hrs. South – 10hrs. West – 10 hrs. North – 8 hrs. or no lag. Courtyard walls can allow air and light to permeate while minimizing negative wind and heat impact.
21. Incorporate wind tower to distribute wind through negative pressure and function as outer air passage through convection. Gas powered central hearth underneath wind tower. Additional fireplaces in each space.

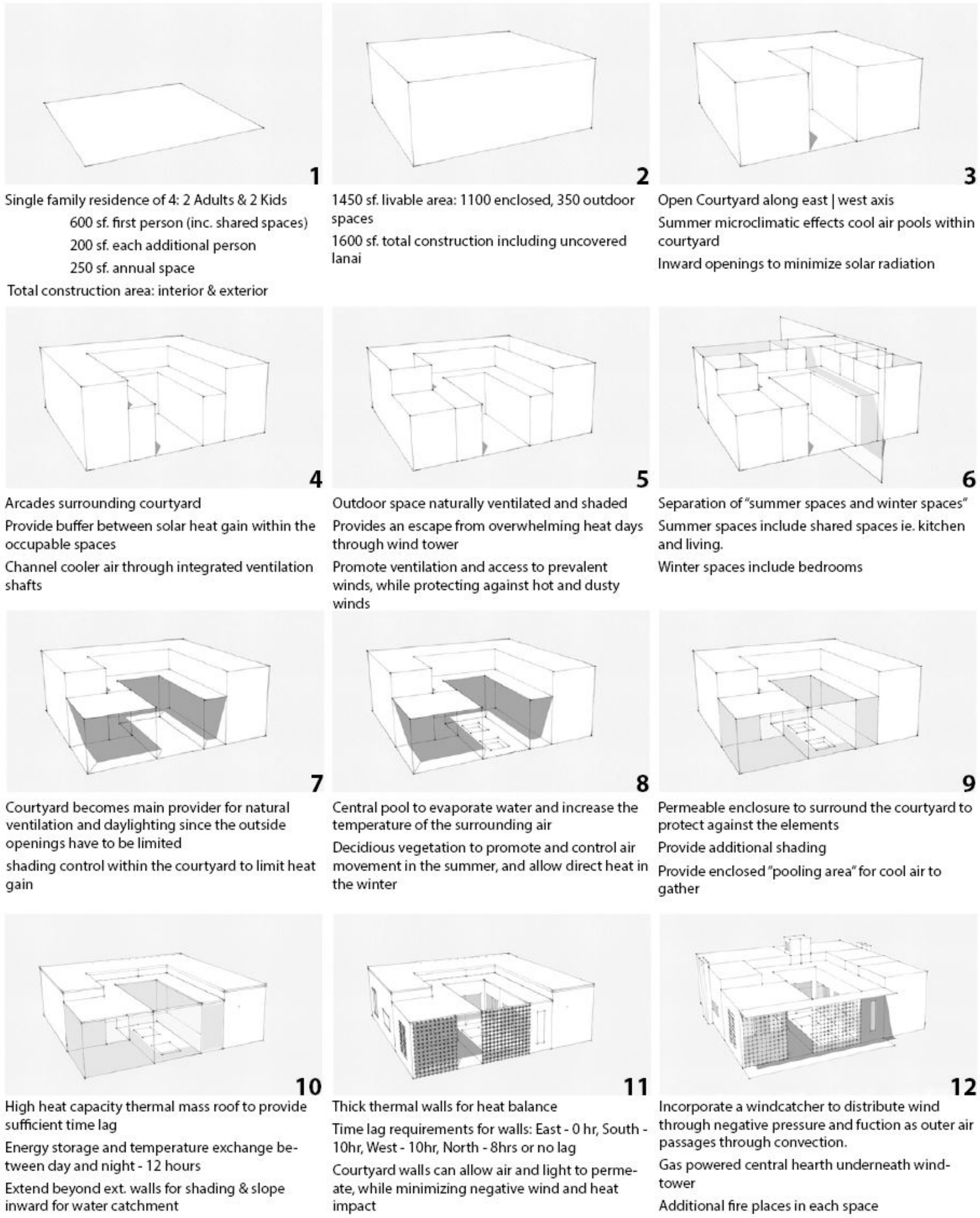


Figure 6.26 – P2 Step-by-step breakdown of vernacular components

Figure 6.27 – scale:3/32” - P1 Passive lighting, heating, and cooling systems breakdown

Anticipated passive lighting, heating and cooling systems:

4. Daylighting focused on shared spaces. No skylights incorporated, window openings provided in all spaces. Open courtyard used for direct lighting into corridor, as well as shading.
5. Heating primarily controlled through thermal massing of walls. Small interior

chimneys provided at private spaces. Hearth located in shared corridor. Solar heat gain anticipated at elevated vault and interior courtyard.

6. Primary cooling strategy implemented at wind tower through stack ventilation. All window openings only wooden louvers, no glass. Doors along open courtyard also louvered. Vegetation and water ‘pool’ for air humidification.

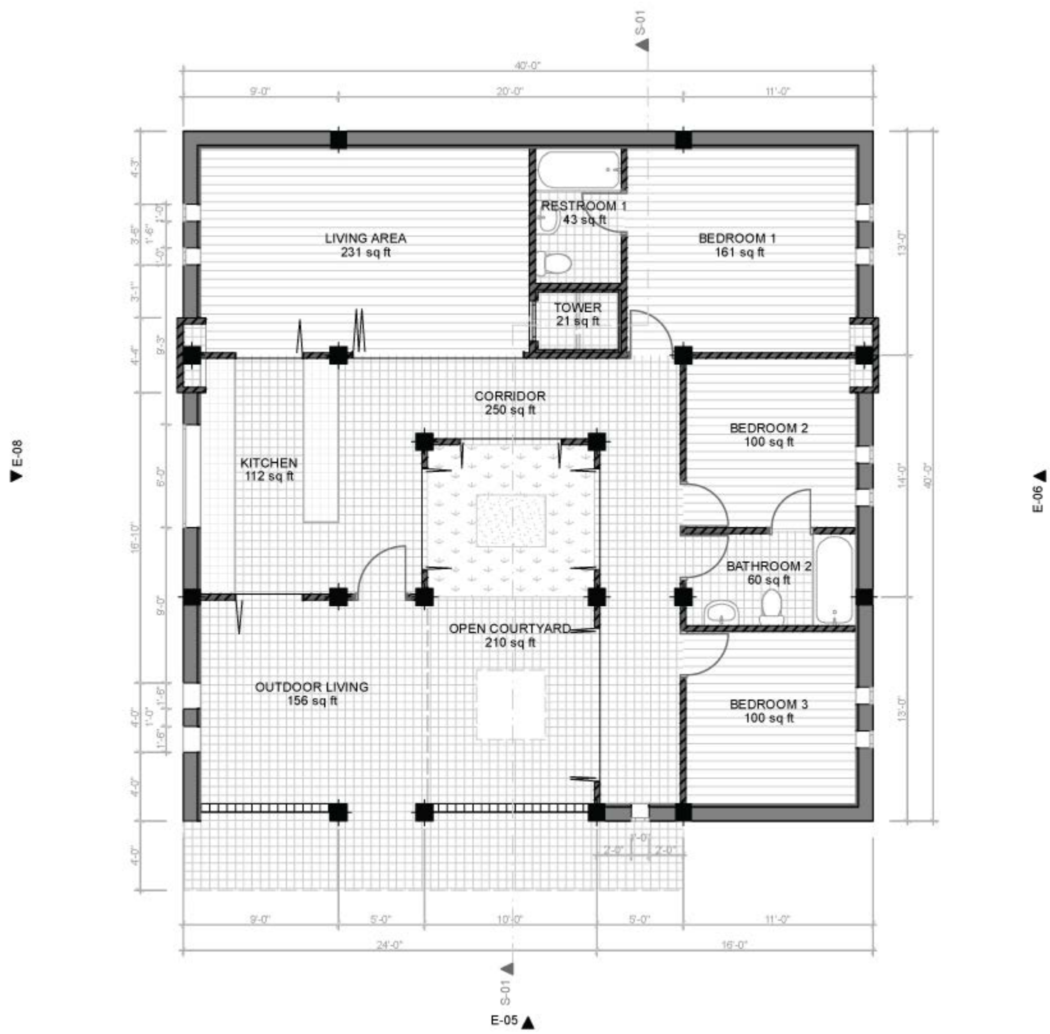


Figure 6.28 – scale:3/32” - P2 Floor Plan

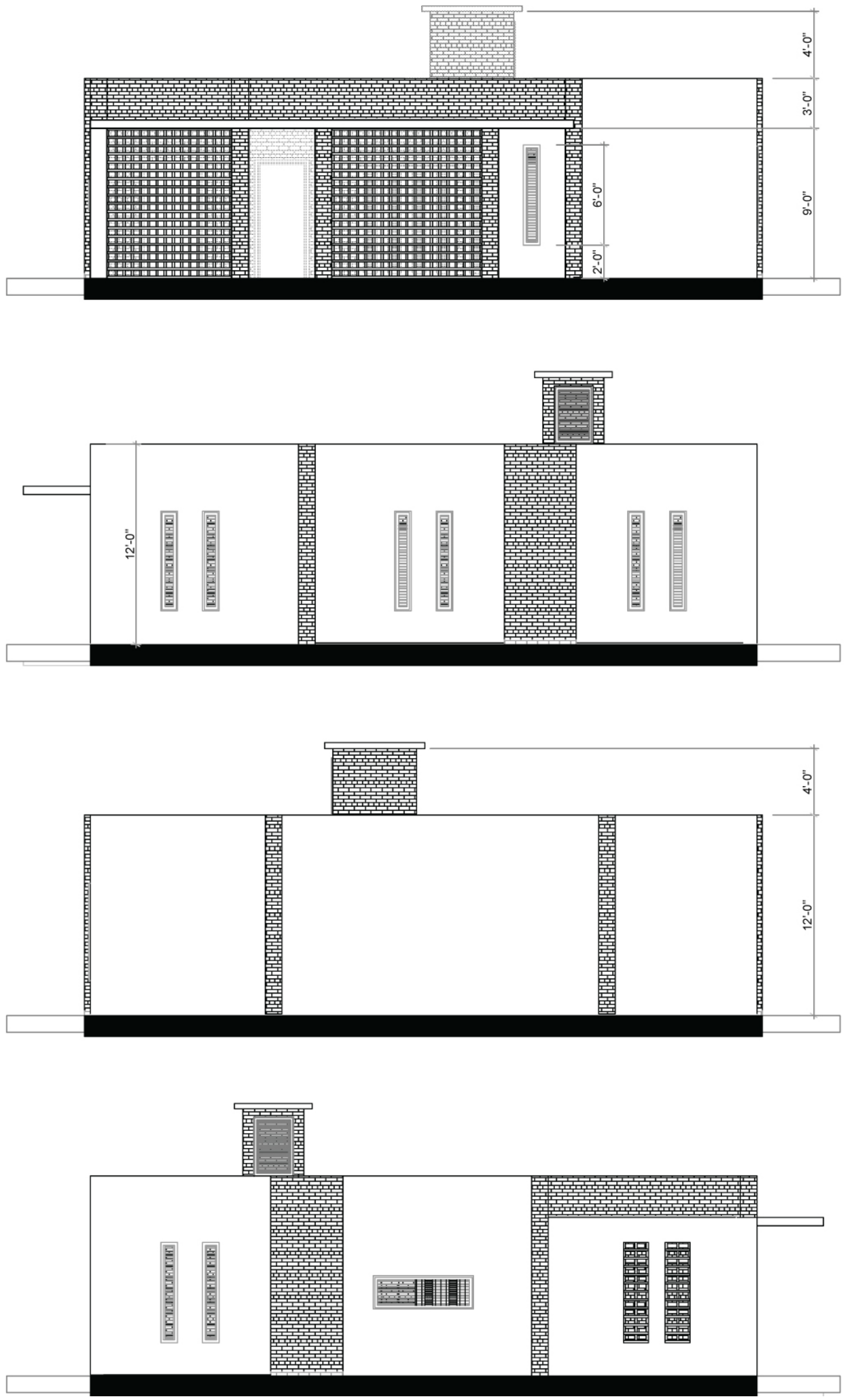


Figure 6.29 – scale:3/32” - P2 Elevations

Figure 6.30 - P2 Rendered Section

Figure 6.31 - P2 Isometric Rendering

Figure 6.32 - P2 Interior rendering at open courtyard

Computational Fluid Dynamic results

To investigate air flow patterns and speeds on the interior of the buildings, computational fluid dynamics, or CFD was used to generate visible patterns and test the performance of the vaulted ceiling and wind tower components within prototypes 1 and 2, respectively during the hot months. CFD modeling is limited to point in time results, for which a single date of July 15th at 3:00 pm was selected. This date provides the strongest hot-month winds with comfortable temperature ranges at a Northeast angle. Local wind speeds were not manipulated and were relative to the external conditions, including topography, ext. walls, and courtyard.

Construction Materials	***Prototype 1***		***Prototype 2***	
Building Type	Single Family Dwelling	*U-Value*	Single Family Dwelling	*U-Value*
Exterior Wall Assembly	Rock & Geothermal	0.0388	Pressed mud mortar	0.2588
Interior Wall Assembly	Solid partition	0.2053	single-leaf brick	0.3954
Ground Floor Assembly	Un-Insulated Solid	0.1243	Un-Insulated Solid	0.1243
Roof Assembly	Dome Roof	0.0561	Flat Roof	0.07453
Doors	Solid Wood	0.4504	Solid Wood	0.4504
Windows	Solid Wood Louvers	0.6629	Solid Wood Louvers	0.6629
Openings	Clear Element	1.0026	Clear Element	1.0026

Area Calculations		***Prototype 1***			***Prototype 2***		
		Floor Area	*Wall Area*	*Openings*	*Floor Area*	*Wall Area*	*Openings*
Living Area	ft^2	228	854.37	116	228	668.5	102
Kitchen	ft^2	182	463	140.5	104	458.5	157
Corridor	ft^2	136	604.5	234.5	245	939	475
Bedroom 1	ft^2	196	539	29.25	168	598	50
Bedroom 2	ft^2	100	379	29.25	100	469	154.5
Bedroom 3	ft^2	100	400	24	100	469	154.5
Restroom 1	ft^2	30	199	21	40	300.5	18
Restroom 2	ft^2	40	260	0	60	0	266
		Floor Area	*Wall Area*	*Openings*	*Floor Area*	*Wall Area*	*Openings*

Figure 6.33 Snapshot of model inputs for both prototypes

Dynamic simulation results undertaken with the thermal simulation package within IES-VE. This tool is able to simulate the performance of a building using real climate data. Dynamic simulation results provide valuable information in relationship to the building materials U-value based performance alone, presented in the figure above. The results were tested based on the hot and cold yearly climatic divisions established in the previous section. The results presented established improved performance in prototype 1 within the hot months, and improved performance in prototype 2 within the cold months.

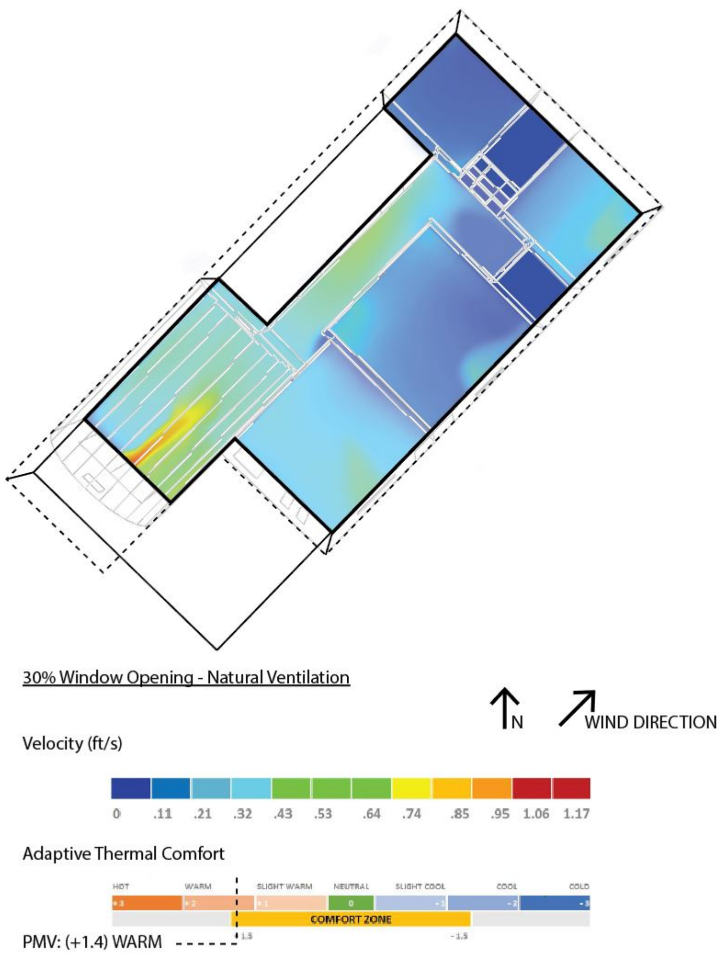


Figure 6.34 Prototype 1 CFD Results on July 15th at 3:00 pm. 30% Window Openings

Natural ventilation can be induced by cross ventilation (wind-driven) or stack ventilation (buoyancy driven). However, CFD analysis solely measures cross ventilation.

Each model was simulated with window opening areas of 30%, through operable louver window and door systems. Protoype 1 was adjusted to account for cross ventilation, while prototype two was adapted for stack ventilation.

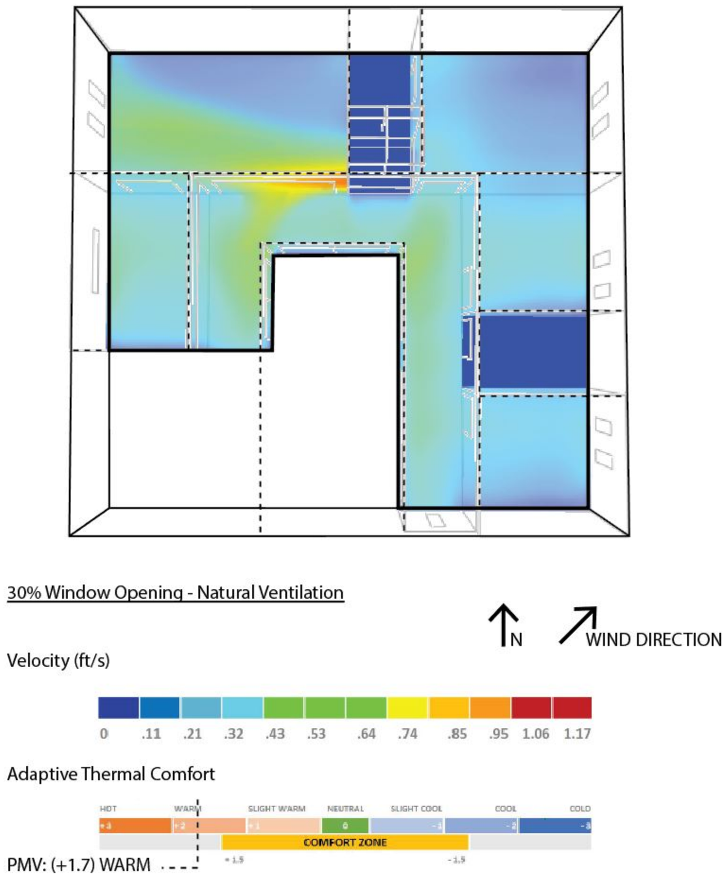


Figure 6.35 Prototype 2 CFD Results on July 15th at 3:00 pm. 30% Window Openings

The results present a visual representation of wind penetration and speed in relationship to the spatial configuration of the prototypes. The exterior courtyards were excluded from the analysis, as well as restrooms were represented as closed off to the main living space, showing a 0 ft/s wind velocity.

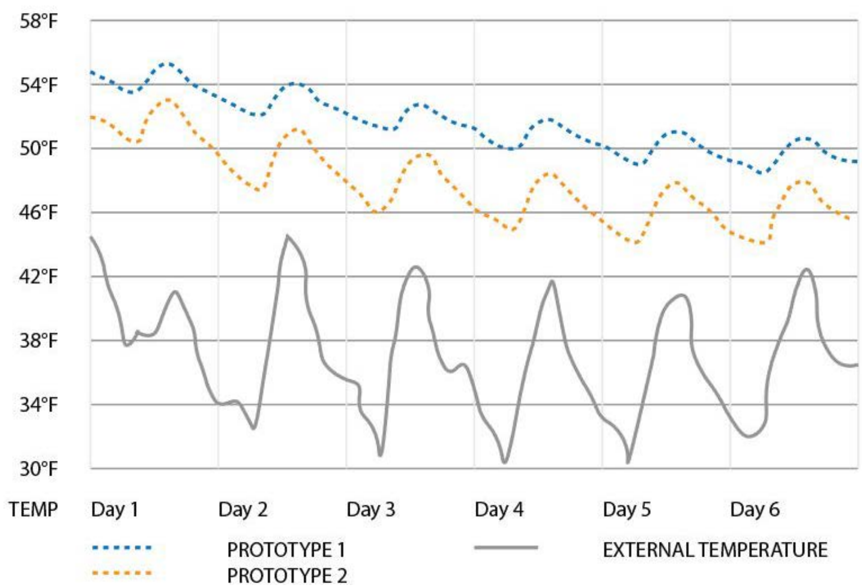


Figure 6.36 Measured external temperature & simulated prototype indoor room temperatures per wall construction. Cold Months, Jan 12-17th

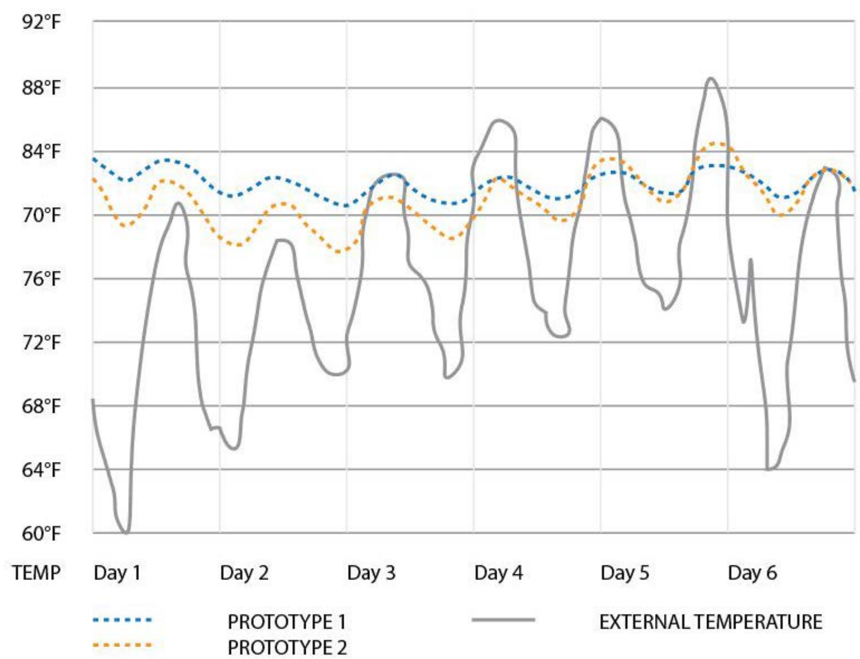


Figure 6.37 Measured external temperature & simulated prototype indoor room temperatures per wall construction. Hot Months, July 12-17th

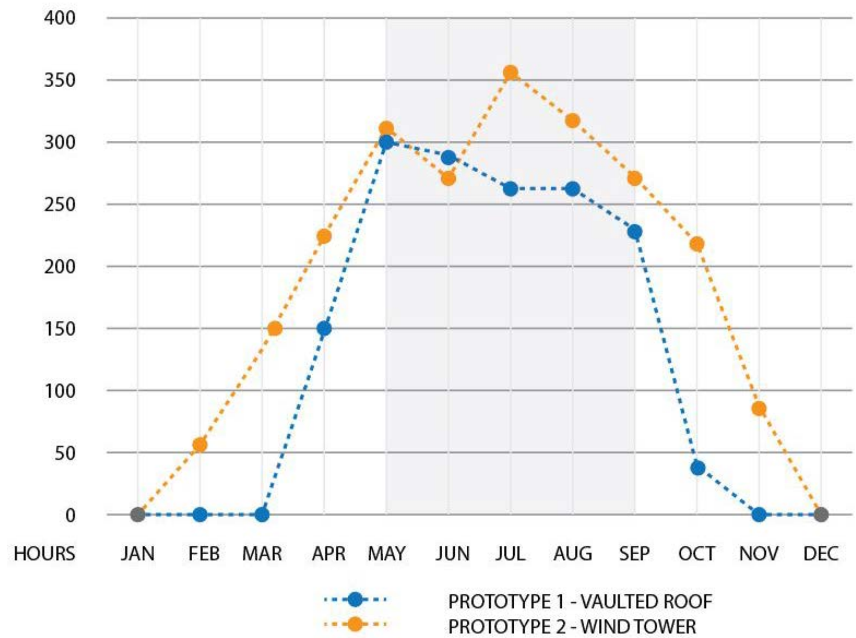


Figure 6.38 Comfort Hours per cooling level of natural ventilation

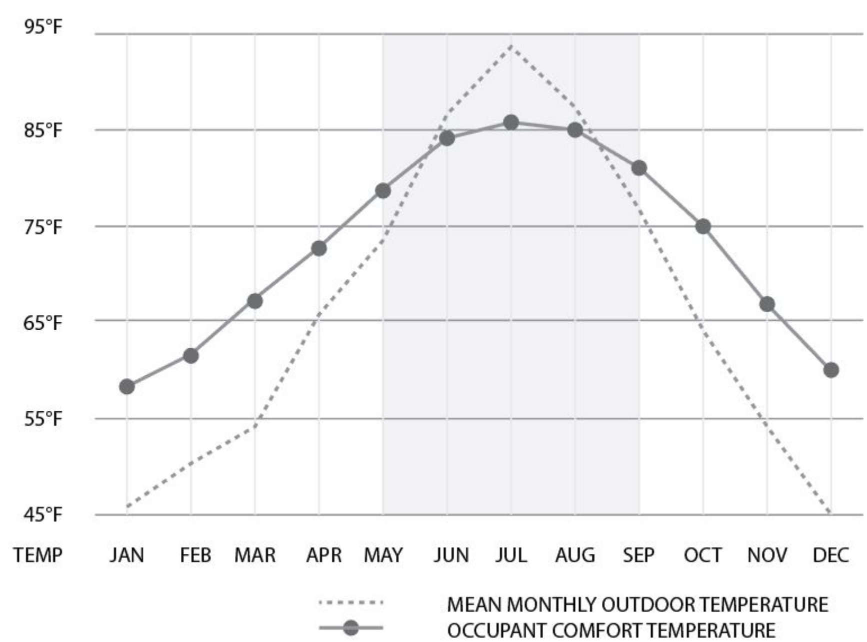


Figure 6.39 Mean monthly Outdoor & Occupant comfort temperature for El Paso, TX

The results demonstrate the improvements upon the adaptive thermal model in when applied to the base model. The predicted mean vote (PMV) total annual hours within the comfort zone. The base model proved very inefficient without the use of central air and natural gas heating systems, with only 26% of annual hours where humans are thermally comfortable. Although with the assumption that with the use of active heating and cooling the range increases to 100% comfort. Both prototypes provided a substantial improvement when incorporating vernacular strategies into the design and materials.

Prototype 1 proved more efficient in cold-months, with primarily geothermal efficiency in retaining heat in winter. Prototype 2 provided more efficient in hot-months with increased ventilation, preventing heat gain.Figure 6.40 compares the results and optimum comfort levels. Although Prototype 1 proved more efficient for winter season, for the heating-dominated location, Prototype 2 outdid the efficiency by 5% due to more balanced comfort control in both cold and hot months.

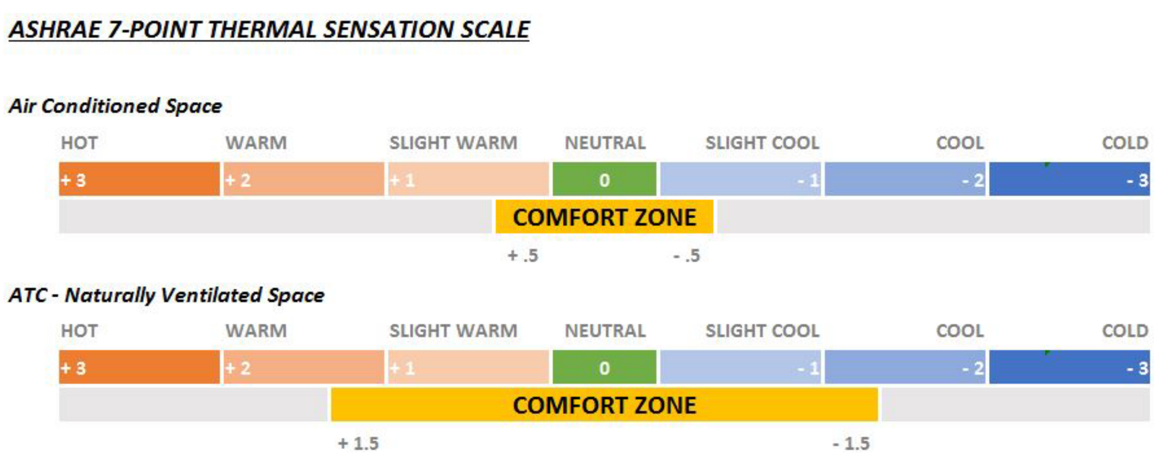


Figure 6.40 ASHRAE 7-Point Extended Thermal Sensation Scale

The initial hypothesis suggested that using random vernacular strategies gathered from the global archetypes would account for a fully thermally-controlled passive residence. Although the results demonstrate a 16-21% deficiency, they significantly improved thermal conditions relative to the ATC metric model proving to be an efficient alternative to the dependence on fully active cooling and heating systems.

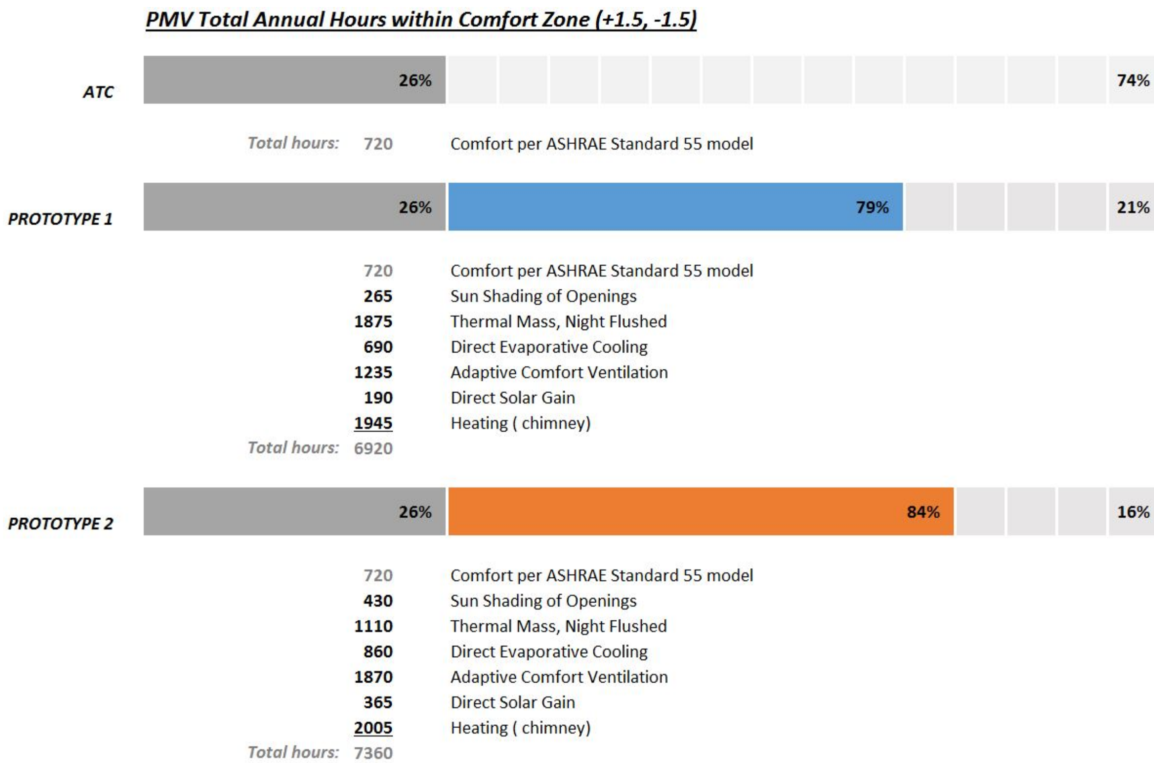


Figure 6.41 Total Annual hours within the predicted median vote (PMV) comfort zone of +1.5 to -1.5 for prototypes and Adaptive Thermal Comfort ASHRAE Standard, plus strategies

Although there is not a vast amount of scholarship available in measuring thermal comfort zone of naturally ventilated spaces within the cold-arid climate classification, the energy modeling systems were used to estimate thermal comfort in relation to one another, the macro scale site, as well as the allowable standards. The results provide the first step of incorporating passive systems, primarily in relationship to ventilation, heat resistance/gain, and humidity control through a focus on the building envelope design.

With further prototype optimization and additional prototype testing, it can be assumed that the number of hours within the comfort zone can be increased upward to 100%. It is important to remember that although the prototypes did result in 79-84% comfort zone, 30% of the users within the acceptable range can still feel uncomfortable, too hot or too cold.

Chapter 7: Discussion

This doctorate project creates and tests a library of global components found in vernacular architecture within cold-arid deserts. Current research in this area deals with analyzing a single archetype and re-applying it in its original context and form. This doctorate project offers a design framework to research, interpret, and design a hybrid response through the lessons of the four major archetypes, tents, huts, domes, and complexes. In turn, to establish through an ecologically sensitive alternative to current housing a theoretical process that can apply to any theoretical location within the global cold-arid deserts.

7.1: Design development

The result of this dissertation is to test the knowledge gathered in the case study library in two ways: test the applicability in today's standards of human comfort scale, as well as apply theoretical guidelines a with step-by-step process derived directly from the component matrix.

					MATERIAL		CONSTRUCTION			STRUCTURE				ROOF		LEVEL			ORIENTATION			BUILDING TYPE				USE	
GEOGRAPHY			LOCATION	NAME	FELT & LEATHER	GRASS	WOOD	EARTH	STONE	SHADE	COURTYARD	TERRACE & PATIO	NARROW ALLEYWAYS	ROOF SHAPE	ROOF OUTLET	PLATFORM	DUGOUT	NATURAL ENCLOSURE	ORIENTATION	OPENINGS	SPATIAL LAYOUT	COMPACT	TENSILE	MULTI-STORY	PORTABLE	SEASONAL	DIURNAL
AMERICA	N	UNITED STATES	CHACO CANYON	MESA VERDE		●	●	●	●	●	●	●	●	●			●	●	●	●		●		●			●
	S	PERU	COLCA VALLEY	COLLAGUA HOUSE		●	●	●	●	●	●	●		●		●				●	●			●			
		CHILE	ATACAMA DESERT	QUINCHE HOUSE		●	●	●												●							
		BOLIVIA	ALTIPLANO	CHIPAYA HOUSE		●	●	●	●					●					●	●	●					●	
AFRICA	N	MOROCCO	DRAA VALLEY	KSOUR, KSAR		●		●	●	●	●	●	●		●		●	●	●	●	●	●		●			
		ALGERIA	MZAB VALLEY	KSOUR,KSAR		●		●	●	●		●	●		●			●	●	●	●	●		●			
	S	SOUTH AFRICA	KAROO HIGHLAND	CORBELLED HUT		●	●		●	●				●	●	●			●	●	●						●
		NAMIBIA	NAMIB DESERT	NAMA HUT	●		●	●	●					●				●			●		●		●		●
ASIA	W	IRAN	YAZD PROVINCE	URBAN COMPLEX		●		●		●	●	●	●	●	●		●	●	●	●	●	●		●			●
		SYRIA	IDLIB STEPPE	CONICAL HOUSE			●	●						●					●	●	●					●	
	C	JORDAN	PETRA	BLACK TENT	●		●							●	●				●	●	●		●		●	●	
		TURKMENISTAN	MARY PROVINCE	CUPOLA HOUSE		●	●	●		●		●		●	●	●				●	●						
	S	AFGHANISTAN	HINDU KUSH	BLACK TENT	●		●	●		●				●			●	●		●			●		●	●	●
		TAJIKISTAN	PAMIR MOUNTAIN	PAMIR HOUSE				●	●	●		●		●	●	●				●	●					●	
	E	INDIA	LEH DESERT	MOUNTAINSIDE COMPLEX			●	●					●	●		●		●		●	●	●					●
		MONGOLIA	GOBI DESERT	GER / YURT	●	●	●	●						●	●				●		●		●		●	●	●
		CHINA	LOESS PLATEAU	CAVE DWELLING		●	●	●		●	●	●	●	●		●		●			●	●					●
AUS	S	AUSTRALIA	EVERARD RANGES	GRASS HUT		●	●			●				●		●	●		●	●	●					●	●

Figure 7.1 Vernacular Matrix of Components

Understanding of social and cultural factors was necessary as an initial introduction to the components to understand why some elements were present within the vernacular scholarship. However, it was difficult to create connections at different levels of social class, material availability, culture, and geographical location. Because of this, it was deemed that the constant within all the sites was the quantifiable similarities of how components addressed solutions to environmental constraints.

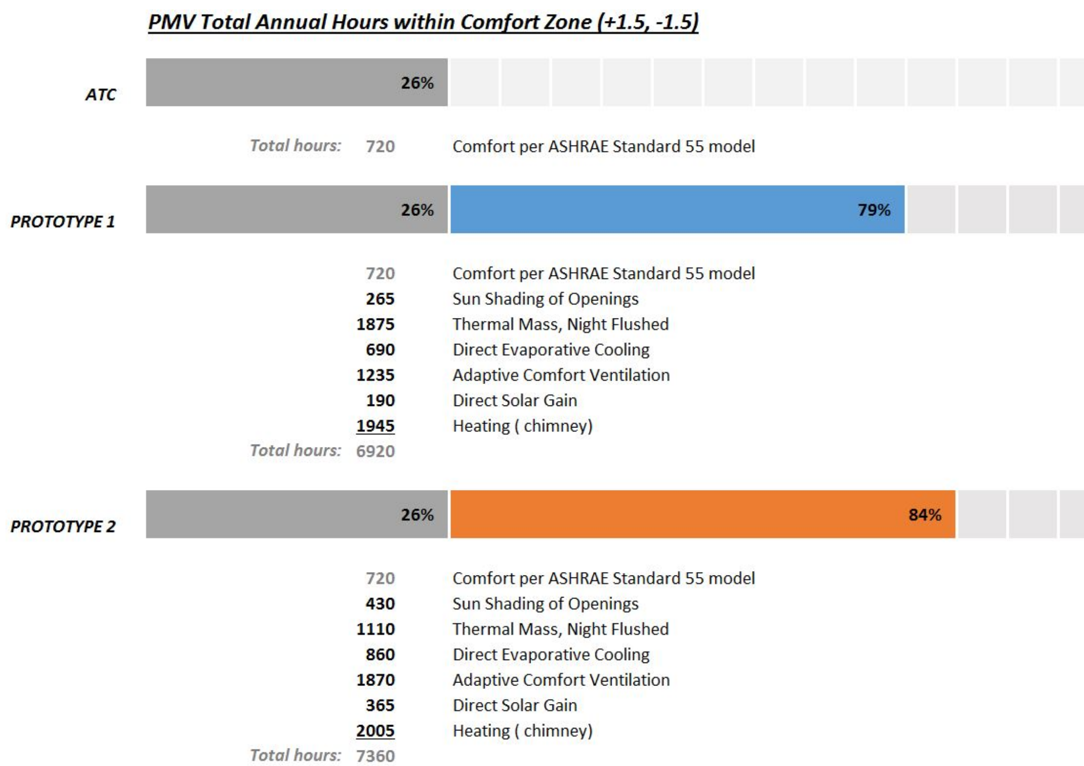
The underlying parameters for this project required an initial understanding of what is known as the cultural landscape, in which a series of selected areas are disseminated not only at a naturally occurring level, but with an emphasis on how the human aspect of the inhabitants of the space molded the landscape in relationship to physical with psychological factors. These cultural, economic, and human self-awareness factors combined with global shared ecological factors, led to the evolution of unique vernacular techniques across the globe.

The ecological basis of this research was through the study of residential vernacular architecture approach found within a specific climate classification of the BWk & BSk cold-arid deserts and gather the fundamental components used to address the climate and provide thermal comfort to its inhabitants. The importance of this scholarship was to generate a matrix of similarities and commonly used components in the desert classification at a global scale. There is plenty of scholarship available of each of the archetype. However, there was no available gathering of the principles, or components, in a single library.

Once the information was gathered, the continuing objective was to assess the functionality of each component and its applicability with today's comfort standards. It is important to note that although some of these systems are still used to this date, not all comply with current lifestyles, resource availability, and response to current thermal performance standards. To test the design parameters, the ASHRAE Standard 55 – Adaptive thermal comfort model was used as the control for determining efficiency in modeled application.

A series of two prototypes were extrapolated from the vernacular framework of passive design strategies, and tested in comparison to a modern style residence within a single point in the cold-arid desert climate, in the city of El Paso, Texas. The prototypes were analyzed in terms of 6 major environmental and individual factors to establish their percentage of time within the comfort zone, in relation to the base sample residence. For this analysis to work, the climate parameters were reduced from a macro global scale to a micro-local scale. Local considerations taken include understanding of economic necessities within the selected culture, housing habits, and family size. Local weather data used monthly average temperatures, solar exposure, wind speed and patterns, and construction materials.

The results present a visual representation of two prototypes that serve as preliminary design diagrams and the actual efficiency of combining global vernacular components.



The initial hypothesis suggested that using random vernacular strategies gathered from the global archetypes would account for a fully thermally-controlled passive residence. Although the results demonstrate a 16-21% deficiency, they significantly improved thermal conditions relative to the ASHRAE 55 adaptive thermal comfort metric model proving to be an efficient alternative to the dependence on fully active cooling and heating systems.

7.2: Future research

The scope of this project cannot demonstrate the effectivity of all vernacular components applied to all sites. The purpose of this paper was not to establish specific criteria to all vernacular archetypes but to provide a scope of knowledge that encompasses a global scale in a concentration of scholarship to be used as the initial framework for future passive design.

Although the introductory energy model simulations did not comply 100% with current thermal comfort standards, prototype 1 and 2 improved the base sample comfort from 26% total hours of comfort to 79-84% hours respectively, simply by incorporating passive vernacular design strategies. Through the concept of merging the cultural landscape with the site ecology, a residence can reduce its dependency on active systems to provide comfort to its users.

Future prototypes can be improved upon by optimizing the relationships of the vernacular components, testing them in sets and determining the most effective relationships. It is important to understand also that although the components gathered all lie within the same Koppen climate classification, cold-arid deserts, there are unique geographical and environmental parameters that will be different when applied to additional sites.

A second use for the prototypes can be used simply as a building framework, that can be brought up to societal standards with incorporation of contemporary systems. The prototypes created are a mixture of vernacular designs that can be improved upon with incorporation of innovative systems, i.e. automatic operable window panes, electrical fans, integrated heating, and cooling, etc. The integration of modern systems unto the vernacular prototypes, rather than a typical modern wood-stud construction base sample, can help aid in building lifecycle, impact on natural resources, and reduction of monthly energy usage and cost.

In conclusion, global similarities and unique interpretations of architecture have evolved through centuries of use and adaptation to culture, geography, and climate within the cold-arid climate. Using a global vernacular framework, passive design can refer to the past solutions to provide a valid architectural solution in relation to human comfort standards. Some endless combinations and adaptations can be conceived upon to develop a highly effective, passive residence.

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